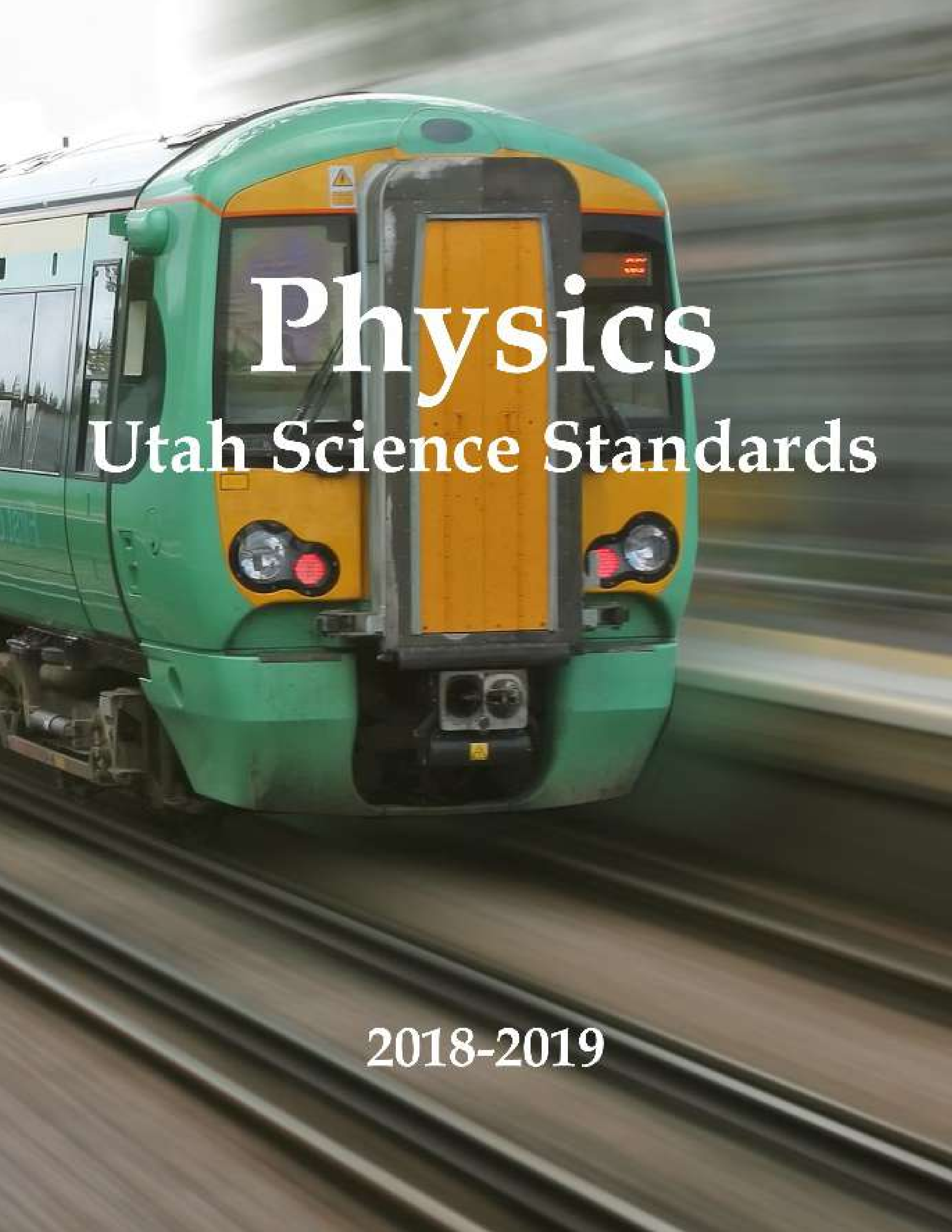

Physics

Utah Science Standards

2018-2019

Physics

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Utah State Board of Education OER
2018-2019

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AUTHOR

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We especially wish to thank the amazing Utah science teachers whose collaborative efforts made the book possible. Thank you for your commitment to science education and Utah students!

cK-12

Students as Scientists

Why Science?

Many students equate science to learning vocabulary terms, labeling pictures, and memorizing facts. Science by nature is much more inclusive and loosely defined. Have you ever asked yourself questions about your surroundings and wondered how or why they are happening? This is science. Science works best when driven by curiosity and innovation. In order for you to experience science in its fullest sense you must take it beyond the textbook and into your everyday experience, but in order to be meaningful there are certain guidelines that can help us. Science is not constrained to Physics, but there are **crosscutting concepts** threaded throughout all scientific disciplines. These include:

- Patterns; i.e. wave actions
- Cause and effect: Mechanism and explanation; i.e. falling objects and gravity
- Scale, proportion, and quantity; i.e. the bigger they are, the harder they fall.
- Systems and system models; i.e. objects in motion
- Energy and matter: Flows, cycles, and conservation; i.e. Energy transformations
- Structure and function; i.e. architecture
- Stability and change; i.e. Newton's first law

When studying any specific scientific discipline you should attempt to keep these crosscutting concepts in mind in order to gain a better perspective of the world as whole and the nature of science. Included in the concepts are the skills and practices that a scientist utilizes. When asking questions about the natural world there are certain skills and practices that can help you generate better conclusions, explanations and inferences.

These practices include:

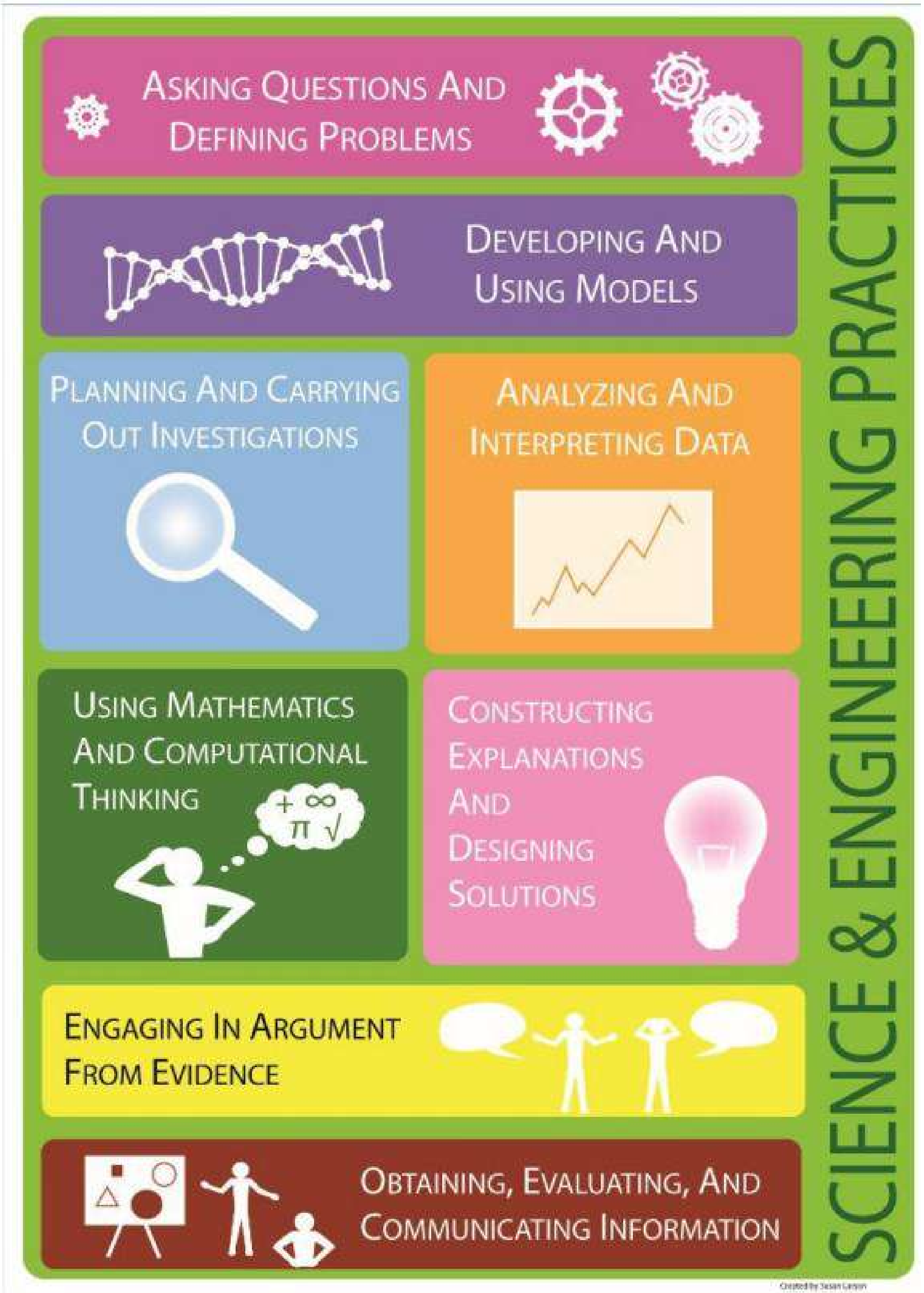
- Asking questions and defining problems
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathematics and computational thinking
- Constructing explanations and designing solutions
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information

While these practices and crosscutting concepts are crucial to your overall success in science, in order to be most meaningful they do need some context. This is where the study of disciplinary core ideas are most impactful. If you study Physics or any other scientific discipline without the crosscutting concepts and scientific practices then you limit yourself to fact memorization and miss how these concepts relate to our everyday life and our society as a whole. Studying individual scientific disciplines are the vehicle for understanding crosscutting concepts and acquiring scientific skills. When individual disciplines are studied within the context of practices and crosscutting concepts they become more meaningful and more impactful.

For example: When looking for solutions to our current energy dependence, it is not a problem to be solved by chemists or physicists or geologists independently. It can only be solved when scientists come together with an understanding of how their independent research relates to the larger problem at hand. If we focus solely upon a few facts or cool phenomenon we can overlook how the study of science can really improve and impact our society and personal experiences.

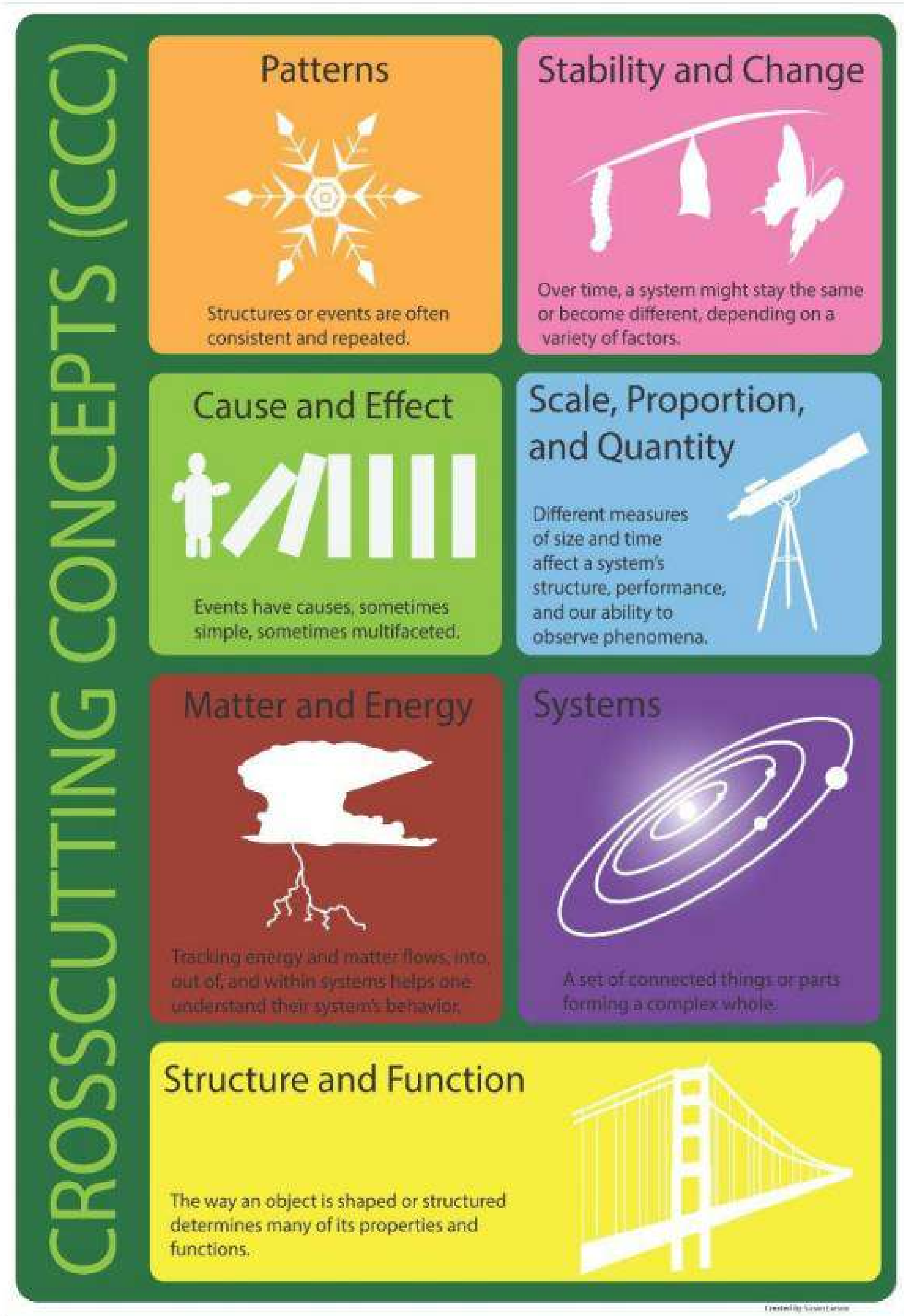
Science and Engineering Practices

Science and Engineering Practices are what scientists do to investigate and explore natural phenomena.



Crosscutting Concepts

Crosscutting Concepts are the tools that scientists use to make sense of natural phenomena.



A Note to Teachers

This Open Educational Resource (OER) textbook has been written specifically for students as a reputable source for them to obtain information aligned to the Utah Physics Standards. The hope is that as teachers use this resource with their students, they keep a record of their suggestions on how to improve the book. Every year, the book will be revised using teacher feedback and with new objectives to improve the book.

If there is feedback you would like to provide to support future writing teams please use the following online survey: http://go.uen.org/b3c

Table of Contents

CHAPTER 1

Standard I: Describing Motion

<u>Chapter Outline</u>

Standard 1: Students will understand how to measure, calculate, and describe the motion of an object in terms of position, time, velocity, and acceleration.

Objective 1: Describe the motion of an object in terms of position, time, and velocity.

1. Calculate the average velocity of a moving object using data obtained from measurements of position of the object at two or more times.
2. Distinguish between distance and displacement.
3. Distinguish between speed and velocity.
4. Determine and compare the average and instantaneous velocity of an object from data showing its position at given times.
5. Collect, graph, and interpret data for position vs. time to describe the motion of an object and compare this motion to the motion of another object.

Objective 2: Analyze the motion of an object in terms of velocity, time, and acceleration.

1. Determine the average acceleration of an object from data showing velocity at given times.

2. Describe the velocity of an object when its acceleration is zero.
3. Collect, graph, and interpret data for velocity vs. time to describe the motion of an object.
4. Describe the acceleration of an object moving in a circular path at constant speed (i.e., constant speed, but changing direction).
5. Analyze the velocity and acceleration of an object over time.

Objective 3: Relate the motion of objects to a frame of reference.

1. Compare the motion of an object relative to two frames of reference.
2. Predict the motion of an object relative to a different frame of reference (e.g., an object dropped from a moving vehicle observed from the vehicle and by a person standing on the sidewalk).
3. Describe how selecting a specific frame of reference can simplify the description of the motion of an object.

Objective 4: Use Newton's first law to explain the motion of an object.

1. Describe the motion of a moving object on which balanced forces are acting.
2. Describe the motion of a stationary object on which balanced forces are acting.
3. Describe the balanced forces acting on a moving object commonly encountered (e.g., forces acting on an automobile moving at constant velocity, forces that maintain a body in an upright position while walking).

1.1 What is Motion?

Objectives

- Distinguish between **distance** and **displacement**.
- Distinguish between **speed** and **velocity**.
- Calculate the **average velocity** of a moving object using data obtained from measurements of **position** of the object at two or more times.
- Determine and compare the **average** and **instantaneous velocity** of an object from data showing its position at given times.
- Collect, graph, and interpret data for position vs. time to describe the motion of an object and compare this motion to the motion of another object.

What is the difference between distance and displacement?

Symbols: Δ anything = final value - initial value (value at time zero)

Scalars:

- $d=|\Delta x1|+|\Delta x2|$
- $v=|v|$
- Distance (in meters, m)
- Speed (in meters per second, m/s)

Vectors:

- $\Delta x=x_f-x_i$ (position displacement)

The symbol Δ (the Greek letter delta) is used to represent "change in". For example, Δt means change in time, or final time – initial time.

We begin our study of motion in the simplest terms we can: motion that takes place along a straight line, which is called one-dimensional motion. A car traveling east, west, north or south, is an example of such motion. When we imagine a car moving along a road we think of the car as represented by a "particle". We define the position of a particle in the same way we would define the position of a point on a number line. Later on we will take up the case of two-dimensional motion; for example, the motion of a baseball through the air.

Scalars and Vectors

Consider the dashboard of a car shown in the figure below. It displays information about the motion of the car. The odometer shows the miles driven by the car during its lifetime. The speedometer shows the instantaneous speed of the car. These values describe "amount or size" or, as we say in physics, "magnitude" but they include no information concerning the direction of the car's motion. In order to describe the motion of an object completely, two pieces of information are required: magnitude (for example, how far, or how fast) and direction.

The odometer (99,000 miles) shows the distance the car has traveled and the speedometer shows the instantaneous speed of the car (40 mi/hr).

In physics a scalar quantity has only magnitude (numerical value): distance - 30 miles and **speed** - 30 mi/hr are two examples of scalar quantities. We use the term vector to describe quantities that have both magnitude and direction. Vectors are represented by arrows: **displacement** - 30 miles due west and velocity - 30 mil/hr due west, are two examples of vectors.

Check Your Understanding

1. Which statement below describes a vector quantity?
   a. A race car moving at 110 mi/hr.
   b. A turtle strolling at 200 cm/min.
   c. An SUV moving at 40 km/hr east.
   d. A wagon heading west.

2. Given the vector 20 Newtons North which would be the magnitude of the vector?
   a. North
   b. 20 Newtons
   c. 20
   d. 20 North

Position is a vector quantity that tells the location of an object. We need to know where things are; this is true whether we are discussing daily life or the complexities of modern

science. Physics defines the location of an object by assigning a position to it. Just as with mathematics, physics typically uses a coordinate system. The coordinate system must have a zero point or "origin" to properly reference position. Since we are discussing one-dimensional motion we will use the simplest coordinate system: a number line with a marked zero, negative values to the left of zero, and positive values to the right of zero. Similarly when using a coordinate system, you can define North as the positive direction and South as negative. You could also define East as positive and West as the negative direction.

When moving to the right and then to the left, we use simple arithmetic to add up the total distance covered. **Distance** is the sum of each segment of the motion. Distance is a scalar quantity. Finding displacement is another matter. To find **displacement**, determine how far and in which direction the object is from the starting point; we call this quantity displacement. Displacement is a vector, since it includes both a magnitude and a direction.

Distance is a scalar quantity giving the positive length between two points. The total length for a series of distances can be computed by adding the absolute values of each length segment. Since distance is found by summing the absolute values of lengths, distance will never be represented as a negative value.

$$\text{Total Distance: } d = |\Delta x_1| + |\Delta x_2| + |\Delta x_3| + \ldots$$

Displacement is the straight line distance in a given direction between the initial and final positions. Displacement is a vector quantity, so direction is included when describing displacement. Displacement can be negative, if the object ends behind (or below) the starting position.

$$\Delta x = x_f - x_i$$

where x_f is the final position of the object and x_i is the initial position of the object.

Successive displacements can be added together as vectors.

$$\text{Total Displacement} = d = \Delta x_1 + \Delta x_2 + \Delta x_3 + \ldots$$

The symbol **d** can be used to describe either distance or displacement, so it is important to recognize which measurement is being discussed. Remember, distance is a scalar quantity and is not dependent on the direction. Displacement is a vector quantity and direction is part of its measurement.

Example 1

Problem: A car goes 120 m north, then 30 m south, then finally 60 m north. How far has the car traveled (distance)? What is the car's net displacement?

Solution:

Distance is the total amount traveled. Thus distance = 120 + 30 + 60 m = 210 m.

$d = x_1 + x_2 + x_3$

$d = 120 \text{ m} + 30 \text{ m} + 60 \text{ m}$

$d = 120 \text{ m}$

Displacement is the amount displaced from the starting position. Generally north is positive and south is negative.

Thus displacement = 120 − 30 + 60 m = 150 m.

Displacement = $\Delta x_1 + \Delta x_2 + \Delta x_3$

$\Delta x = 120 \text{ m} + (-30 \text{ m}) + 60 \text{ m}$

Check Your Understanding

3. Write a paragraph explaining the difference between distance and displacement.

4. You're trying to predict how long it's going to take to get to Los Angeles for the long weekend. Are you more interested in the distance you'll travel or your displacement? Explain your answer.

<u>What is the difference between speed and velocity?</u>

Key Equation: Average Velocity

$$v_{avg} = \frac{\text{displacement}}{\text{change in time}} = \frac{\Delta x}{\Delta t} = \frac{d}{t}$$

Average Speed and Instantaneous Speed

Suppose you are traveling along a long straight highway. You start driving and, an hour later, you are 100 km away. Your average speed is 100 km/hr (kilometers per hour). The information you have is time and distance. You can calculate your average speed by dividing the distance you've traveled by the time of travel.

Average speed: Total distance traveled divided by total elapsed time

During the hour that this trip took, your speedometer may have had many different readings. You might have been traveling faster during the first part of the hour, and then slower in the second half. The reading on the speedometer at some instance is your **instantaneous speed**. Instantaneous speed is the speed at a specific time.

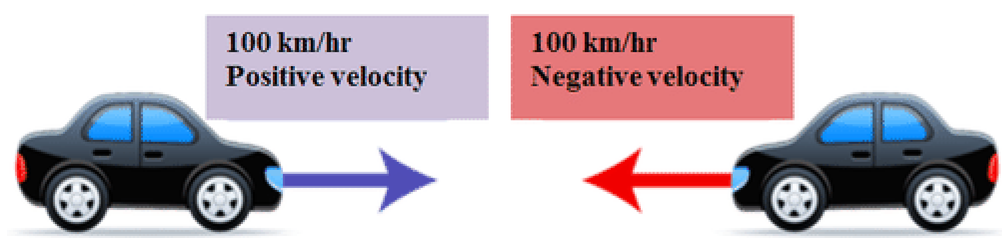
If you go back on a return trip, the calculation of the speed is the same. The result is still 100 km/hr. Like distance, discussed in the previous section, speed is a scalar quantity and thus always positive. The speedometer reading is the same no matter what direction you are driving in. Speed cannot provide information about direction, so speed is a scalar quantity.

Average Velocity

Velocity is different than speed because velocity is a vector quantity and as such will have both a magnitude and a direction.

- Velocity is similar to speed, but it also includes a direction.
- Velocity is the change in position divided by the change in time.
- Change of position can be either positive or negative, so velocity can be positive or negative.

In the example above, the velocity on the outbound trip is +100 km/hr, while the velocity on the return trip is -100 km/hr (see the figure below for detailed calculations).



Velocity vectors on cars indicating direction and magnitude.

Check Your Understanding

5. In the example above, the round trip speed and velocity are:
   a. the same
   b. different

6. The average speed for the entire trip is:
   a. 0 km/hr
   b. 100 km/hr
   c. 200 km/hr

7. The average velocity for the round trip is: (Hint, consider the displacement)
   a. 0 km/hr
   b. +100 km/hr
   c. -200 km/hr

Determining Average Velocity

If the motion is always in the same direction, the average velocity will have the same numerical value as the average speed, except that a direction of motion must also be given.

If motion changes direction, the average velocity will be different than the average speed. Average velocity depends on the total displacement, defined as the line from the initial position to the final position. For example, if a car starts its trip in Saint George and drives to Salt Lake City, it has a positive average velocity (because it is driving north). If the car then returns to St. George, the average velocity for the entire trip would be zero, because its final position and initial position are identical.

Check Your Understanding

8. A car moves due east at 30 miles per hour for 45 min, turns around, and moves due west at 40 miles per hour for 60 minutes. What is the average velocity for the entire trip?

9. Pacific loggerhead sea turtles migrate over 12,000 km (7,500 miles) between nesting beaches in Japan and feeding grounds off the coast of Mexico. If the average velocity of a loggerhead is about 45 km/day toward Mexico, how long does it take for it to complete the distance of a one-way migration?

10. Calculate the average velocity of a car that started at the origin and traveled 300 m west in 10 seconds.

11. Calculate the average velocity of a toy car that started at a point 25 m west of the origin and traveled to a point that is 35 m east of the origin in 20 seconds.

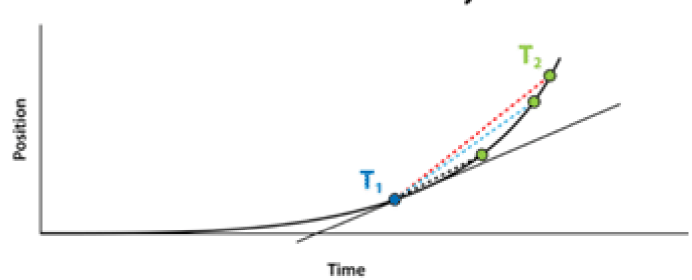
What is the difference between average and instantaneous velocity?

As we said earlier, instantaneous speed is like the reading of a car's speedometer. It is the speed at any exact point in time. Instantaneous velocity refers to velocity at a specific time, such as t =3.5 s. It is like the reading of a speedometer combined with a pointer for current direction.

In practice, we cannot find a truly instantaneous velocity. Instead, we find an average velocity over smaller and smaller intervals of time. For example, a modern car speedometer works by measuring the fraction of a second it takes for the car's wheels to turn once. For driving, this is close to instantaneous. When we measure average velocity over a smaller and smaller intervals of time (Δt), we get closer and closer to instantaneous velocity.

The diagram below shows the position of an object at the times T_2, 5.00 s and T_1, 3.00 s. If $T_1$is held fixed and T_2 permitted to approach T_1, the slope of the line between T_2 and T_1 progressively comes closer to the slope of a tangent line through T_1. The slope of the line through T_1 is called the instantaneous velocity at T_1. The slope of the tangent line to a curve in a position-time graph gives the instantaneous velocity.

How Average Velocity Approximates Instantaneous Velocity

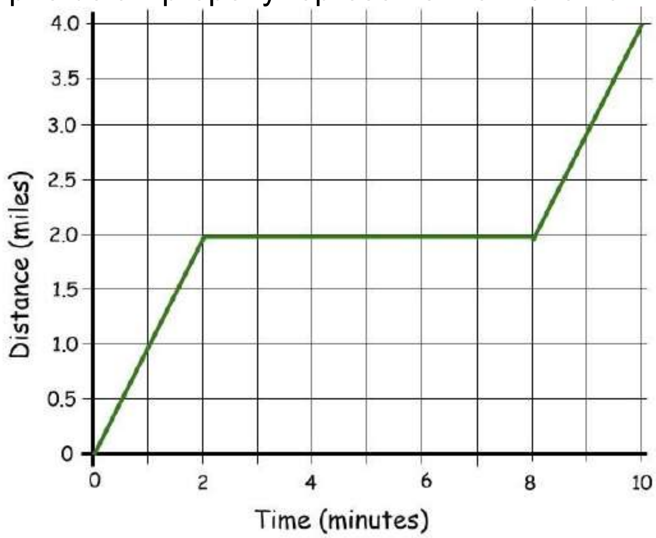


As T_2 approaches T_1 the tangent line through T_1 is approximated. The slope of this tangent line represents velocity.

How can graphs be used to describe motion?

Mr. Jones lives on the same road as the high school where he works. During his morning commute, Mr. Jones drives two miles in two minutes, to reach the donut shop. He spends six minutes at the shop and while there, realizes he's forgotten his lunch at home. So he returns home, again covering two miles in two minutes.

Which of the two graphs below properly represents the motion of Mr. Jones' car?



Graph 1. This graph shows what the odometer would display: Mr. Jones traveled four miles. What it does not display is the current location of Mr. Jones' car.

Graph 2. This graph shows the location of the car. You can tell from reading the graph that the car has returned to where it started. However, determining the distance the car traveled from this graph is not that obvious.

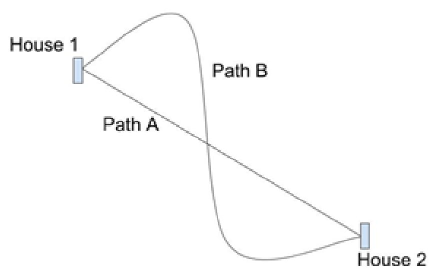
Which graph is correct?

Actually both are correct; they simply provide different information.
Graph 1 in the figure displays the distance traveled by the car as a function of time, while Graph 2 displays the position of the car as a function of time. After ten minutes the car has traveled four miles (Graph 1 in Figure above), and it is back where it started (Graph 2 in Figure above).

Using Graph 2 in the figure above, the total distance the car traveled can be found by adding up the segments of its motion, while the final position of the car can immediately be read from the graph. Using Graph 1 in the figure above, the total distance the car traveled can immediately be read from the graph, but there is no way to determine the car's final position, because direction is not shown. Graph 2 in the figure above, the position versus time graph, can be used to find velocity, position, and displacement.

Check Your Understanding

12. Two bicyclists travel from House 1 to House 2 as in seen in the figure below. Path A is a straight and Path B is a curved path. Which path has the greater displacement?



Position Time Graphs

We will continue with the story of Mr. Jones and use the data from his story to now discuss speed and velocity and see what we can find. A table was made to show Mr. Jones's movement from his home to the donut store and back home.

Time Interval (min)	Distance (miles)	Speed (miles/min)	Time interval (min)	Displacement (miles)	Average velocity (miles/min)
[0, 2]	2	1.0	[0, 2]	+2	+1
[2, 8]	0	0.0	[2 , 8]	0	0
[8, 10]	2	1.0	[8, 10]	-2	-1

Look back at the position vs. time graph for Mr. Jones. Mr. Jones' velocity during the time interval [0, 2] is calculated using the definition of average velocity:

$$v_{avg} = \frac{\text{displacement}}{\text{change in time}} = \frac{+2\text{miles}}{2\text{min}} = +1\text{mile/min}$$

What is the slope of the line for the interval [0, 2]?

A bit of thought would lead you to the conclusion that the slope is identical to the definition of velocity, as long as the units are included. In fact, the units of velocity are an aid in determining how to calculate velocity; miles "over" minutes imply division. This is a very important result: any slope in a position vs. time graph has units of displacement/time. Therefore, the slope of the line in a position-time graph is velocity. During the interval [8, 10], the slope of the line is negative. We can immediately surmise that the motion is toward the left on a conventional number line. During the interval [2, 8], the line is horizontal, so the slope is zero, which in turn indicates that the velocity is also zero. This conclusion makes sense physically; since Mr. Jones (and his car) are at the same position during the time interval [2, 8]. If his position is not changing, then of course, he's not moving. So his velocity must be zero.

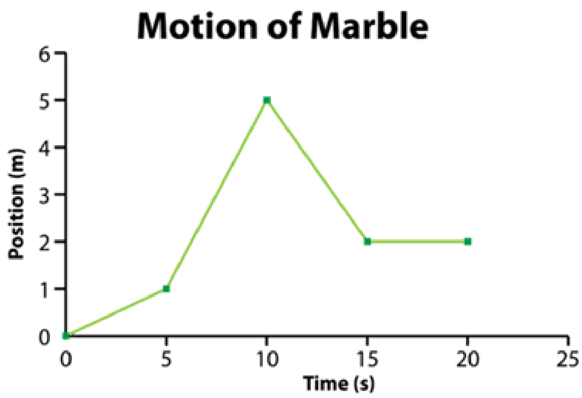
Let's state some general conclusions regarding position-time graphs, using the sign conventions of a number line.

- A positive slope indicates positive velocity; motion is in the positive direction (up, right, north, east, forward, etc.)
- A negative slope indicates negative velocity; motion is in the negative direction (down, left, south, west, backwards, etc.)
- A horizontal line indicates zero velocity, the position remains unchanged and the displacement is also zero.

Check Your Understanding

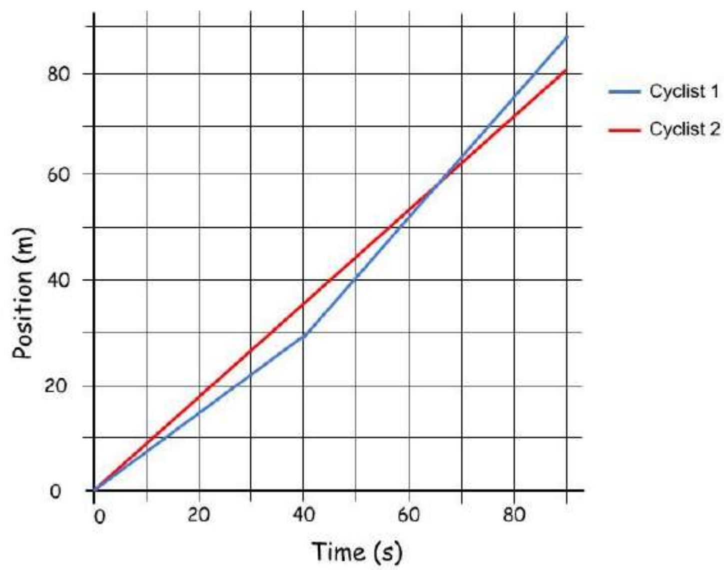
13. An ant travels with constant velocity from position +10 m to position -15 m in a time of 5 s; it instantaneously turns around, and moves from position -15 m to position +3 m with constant velocity, in a time of 6 s. Plot the ant's motion in a position-time graph and indicate the ant's velocity for each interval.

14. The motion of a rolling marble is represented in the position-time graph in the figure below.



Write a sentence or two that describes the marble's motion.

15. Two cyclists coast down a hill. Use the following position vs time graph to answer the questions.



a) Which cyclist has the greatest average velocity over the entire trip down the hill?

b) Which cyclist is has the greatest instantaneous velocity at 55 seconds?

c) Is either cyclist traveling at a constant velocity? How do you know?

Answers to Check Your Understanding:

1. c. Since both speed and direction are given. Speed is the 40 km/hr; east is the direction. Together, speed and direction become velocity.
2. b. The direction is North and the number needs correct units, so 20 Newtons would be the magnitude.
3. Answers will vary, but may include comments about distance being a scalar quantity and displacement being a vector. Distance does not include direction, while displacement does. You might also comment that distance cannot be a negative value, but displacement can be negative.
4. If you are driving, you are interested in the distance that you cover, because the roads that you will be taking are not a direct route to Los Angeles.
5. b. The distance is 200 km, but the displacement is 0 km.
6. b. The average speed is 200 km/2 hrs=100 km/h.
7. a. The displacement is zero, therefore 0 km / 2 hrs = 0 km/hr

8. 10.0 mi/hr
    - East displacement: 30 mi/hr x 0.75 hr = +22.5 miles
    - West displacement: −40 mi/hr x 1 hr = −40 miles
    - Total displacement: −40+(+22.5) = −17.5 miles
    - Total time: 1.75 hours
    - Average velocity = −17.5 miles / 1.75 hours = −10.0 mi/hr

9. 267 days

Using $v_{avg}=\frac{d}{t}$ and solving for t you get $t=\frac{d}{v_{avg}}$

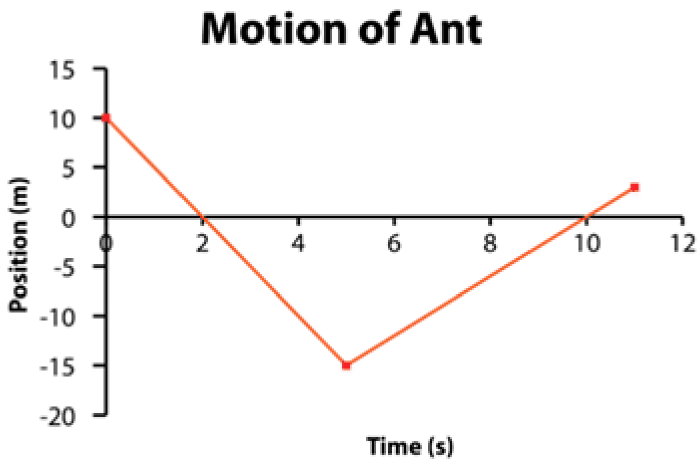
$$t=\frac{12000km}{45\ km/hr}=267\ days$$

10. 30 m/s west

11. 3 m/s east

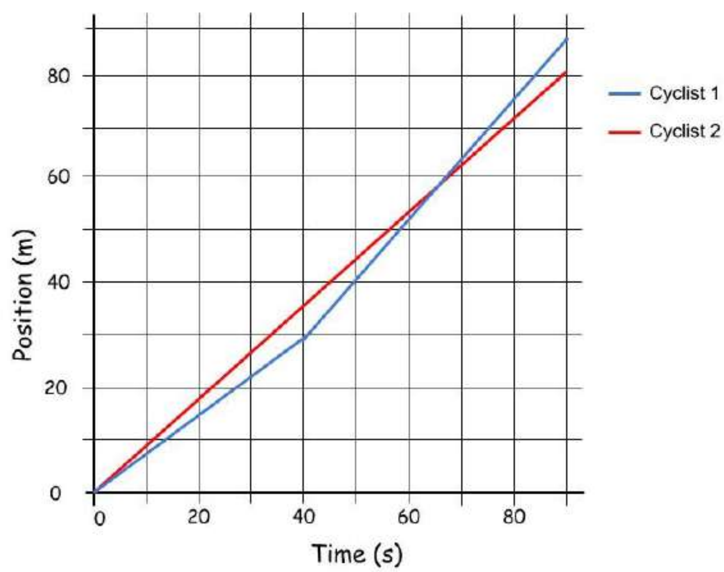
12. They are the same. Consider the definition of displacement: $\Delta x = x_f - x_i$. Since the initial and final positions for both paths are identical, the displacement must be the same for paths A and B.

13. The ant has a velocity of -5 m/s over the first five seconds and a velocity of +3 m/s over the last 6 seconds (The graph is shown next).



14. During the first 5 seconds the marble rolls to the right, slowly; during the next five seconds it continues rolling to the right but faster; during the next five seconds the marble rolls to the left a bit slower than during the previous five seconds; during last five seconds the marble is stationary.

15.



a. Cyclist 1 has the greatest average velocity over the whole trip.

$$v_1 = \frac{d}{t} = \frac{88m}{90s} = 0.98m/s$$

$$v_2 = \frac{d}{t} = \frac{81m}{90s} = 0.90m/s$$

b. By looking at the graph we can see which line has the greatest slope at 55 seconds. Cyclist 2 has the greatest (steepest) slope which is the greatest instantaneous velocity.

c. Yes, cyclist 2 has a constant velocity. This is shown because the graph for cyclist has a constant slope, and therefore a constant velocity.

1.2 Velocity, Time and Acceleration

Objectives

- Determine the average acceleration of an object from data showing velocity at given times.
- Describe the velocity of an object when its acceleration is zero.
- Collect, graph, and interpret data for velocity vs. time to describe the motion of an object.
- Describe the acceleration of an object moving in a circular path at constant speed (i.e., constant speed, but changing direction).
- Analyze the velocity and acceleration of an object over time.

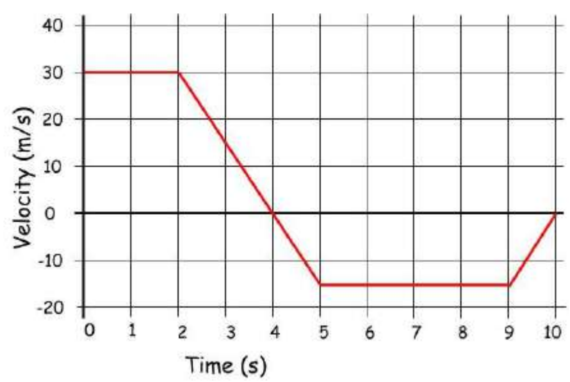
What is average acceleration?

Key Equation: Average Acceleration

$$a_{avg} = \frac{\text{change in velocity}}{\text{change in time}} = \frac{\Delta v}{\Delta t}$$

In everyday life, we use "acceleration" to mean that an object is getting faster - i.e. greater speed. In physics, though, we use "acceleration" to mean any change in velocity. That means speeding up as well as slowing down or turning. Because velocity is a vector, it has direction. So a change in direction is a change in velocity. On a car, using the accelerator pedal is accelerating, but so is using the brakes or the steering wheel.

To see what a change of velocity means, it can be helpful to represent an object's motion with a velocity-time graph. This is extremely useful in determining acceleration and displacement.



This figure shows the velocity of a car over a time interval of 10 sec. When the velocity is above the x-axis, the car is moving to the right (or in the positive direction). When the velocity is below the x-axis, the car is moving to the left (or in the negative direction).

Average acceleration is a change in velocity divided by change in time, which is the slope of a line on a velocity vs. time graph. In the graph shown above, there are times when the car has a zero acceleration (between t = 0 sec and t = 2 sec and again from t = 5 sec to t = 9 sec).

This means that the car has no change in velocity for that interval of time. It doesn't mean that the car isn't moving – it just means that the car is not changing its speed or direction. The car has a positive acceleration between t = 9 sec and t = 10 sec. This means that the velocity of the car is increasing. It doesn't always mean that the car is speeding up. Sometimes, it means that the car is slowing down while moving backwards. This car has a negative acceleration between t = 2 sec and t = 5 sec. This means that the car's velocity is decreasing over that time interval. If the rate of change in the velocity is uniform, then the acceleration is uniform as well.

Note: uniform and constant mean the same thing. We will consider acceleration to be constant in our examples, unless otherwise stated.

Check Your Understanding

1. How can braking (like using the hand brakes on a bicycle) provide for both negative (backward) and positive (forward) acceleration?

2. How can you have a negative acceleration without braking?

3. A car is traveling north on the freeway. It slows down as it reaches traffic. What is the direction of the velocity vector? What is the direction of the acceleration vector?

Acceleration

As common as the term acceleration is, there is a good deal of confusion surrounding the concept. Acceleration only describes how the velocity of an object is changing. It doesn't describe what the velocity is at that moment. An object can have an acceleration and simultaneously have a zero velocity. For example, when a ball is thrown upward, it

slows down as it moves upward. When the ball reaches its peak height, it stops as it changes direction and starts to fall downward. The acceleration due to gravity of the ball in the air is constant ($9.8 m/s^2$), even when it is stopped. It's velocity changes from positive to negative. Since the velocity is changing, there is an acceleration on the ball. The velocity of an object at any instant (think of the speedometer in your car) gives no information in determining the object's acceleration, only the rate of change of velocity can be used to determine the object's acceleration.

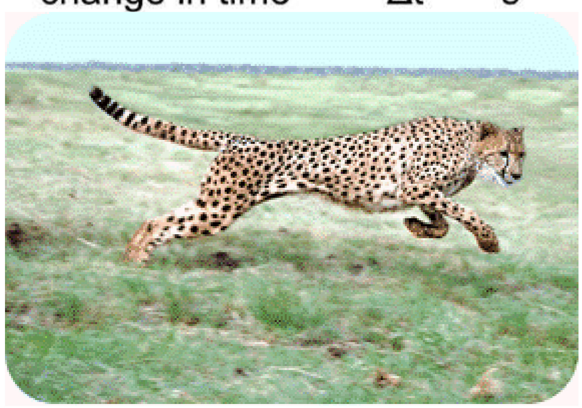
Thinking about Acceleration

Suppose that a cheetah, starting from rest, has an acceleration of over 33 km/hr/s, this means that it is increasing its speed by 33 kilometers per hour every second. So after one second, the cheetah has speed of 33 km/hr, after two seconds, its speed is 66 km/h, and after three seconds, its speed is 99 km/hr.

The cheetah increases its velocity by an average of 33 km/hr every second. The units help to explain that acceleration depends upon the changing rate of velocity. 33 km/hr is about the same as 9.2 m/s (meters per second). So an acceleration of 33 km/hr per second is 9.2 m/s per second. This is expressed as $9.2 m/s^2$.

Using dimensional analysis, we can see this from the formula for acceleration:

$$a_{avg} = \frac{\text{change in velocity}}{\text{change in time}} = \frac{\Delta v}{\Delta t} = \frac{m/s}{s} = \frac{m}{s^2}$$



The cheetah is the fastest land animal.

Check out the following link about acceleration. This website describes acceleration and free fall in more depth. There are some interactives and animations about acceleration.

- http://go.uen.org/b3m

Check Your Understanding

4. Thompson's gazelle can reach a speed of 65 km/hr in 4 seconds. What is its acceleration in m/s^2? (Use the conversion 1 km/hr = 0.2778 m/s)

5. A Thompson's gazelle has a maximum acceleration of $4.5 m/s^2$. At this acceleration, how much time is required for it to reach a speed of 40 km/hr?

6. Can an object have a positive velocity and a negative acceleration?

7. Can an object have a positive velocity and a zero acceleration?

8. Can an object have a zero velocity and a positive acceleration?

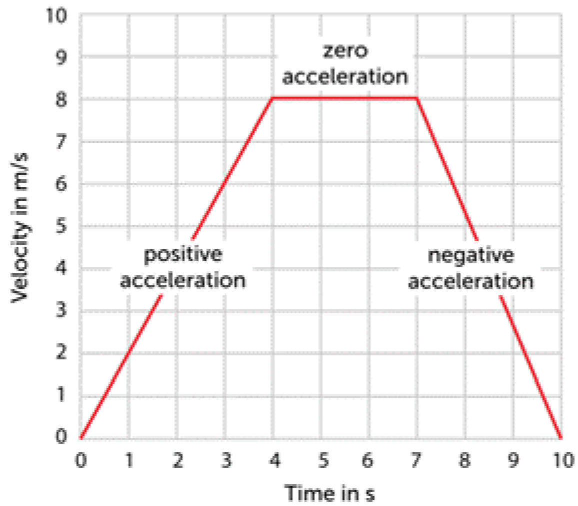
What is the motion of an object with zero acceleration?

The sprinter in this image is just taking off from the starting blocks to run a short race down a straight track. She starts in a burst of speed and will pick up even more speed during the first few seconds of the race. She'll keep running at top speed until she crosses the finish line. Only then will she slow down. Velocity is a measure of both speed and direction of motion. A change in velocity is called acceleration. In the case of the sprinter, she accelerates until she hits her top speed as she runs down the track because her speed is changing although her direction stays the same. When she reaches her top speed and stays at that speed for the majority of the race, she has no acceleration, because she is not changing her speed or her direction. When she crosses the finish line, she has an acceleration again, because her speed will decrease as she comes to a stop after the race.

Plotting Velocity vs. Time

The changing velocity of the sprinter — or of any other moving person or object — can be represented by a velocity-time graph like the one in the figure below for the sprinter. A velocity-time graph shows how velocity changes over time.

The sprinter's velocity increases for the first 4 seconds of the race, it remains constant for the next 3 seconds, and it decreases during the last 3 seconds after she crosses the finish line.



Acceleration and Slope

Remember that in a velocity-time graph, acceleration is represented by the slope (change in velocity over change in time), or steepness, of the graph line. If the line slopes upward, like the line between 0 and 4 seconds in the graph above, velocity is increasing, so acceleration is positive. If the line is horizontal, as it is between 4 and 7 seconds, velocity is constant and acceleration is zero. If the line slopes downward, like the line between 7 and 10 seconds, velocity is decreasing and acceleration is negative. Reminder slope is rise divided by run.

Q: Assume that another sprinter is running the same race. The other runner reaches a top velocity of 9 m/s in 4 seconds after the start of the race. How would the first 4 seconds of the velocity-time graph for this runner be different from the graph above?

A: The graph line for this runner during seconds 0–4 would be steeper (have a greater slope). This would show that acceleration is greater during this time period for the other sprinter. The original runner had a slope of 8 m/s in 4 s (or 2m/s^2*) and the second runner has a slope of 9 m/s in 4 s (or 2.25*m/s^2*).*

Check Your Understanding

9. What does the slope of a velocity versus time graph represents?

10. On a velocity vs. time graph, what does a positive slope, zero slope, and negative slope represent?

11. In the velocity-time graph above, the sprinter reaches a velocity of 2 m/s in just 1 second. At a constant rate of acceleration, how long does it take for her to double this velocity? What is her acceleration during this time period?

12. Question: Create a velocity-time graph by plotting the data in the table below.

Velocity (m/s)	Time (s)
10	1
30	2
50	3
40	4
40	5

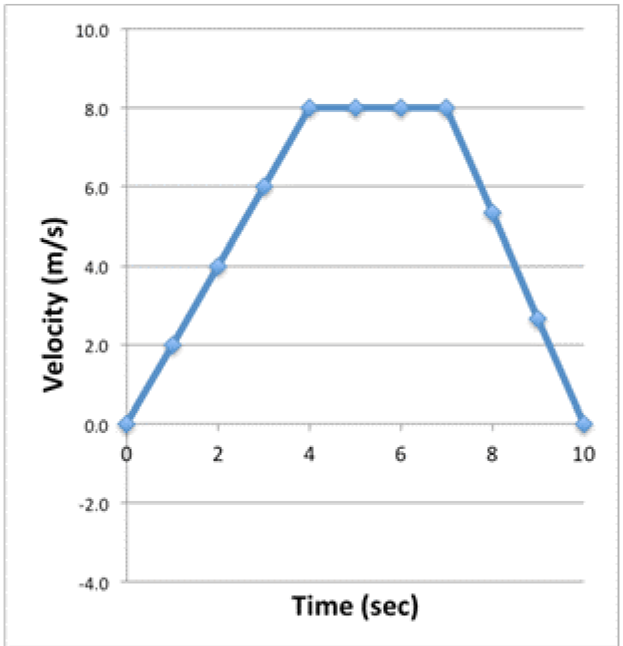
13. Using the velocity-time graph that you created in problem #3, determine if the acceleration is constant. If it is not constant, describe the acceleration of the object.

The following website explains motion graphs. It addresses constant and changing velocity, the importance of slope, and comparing the velocities of objects.

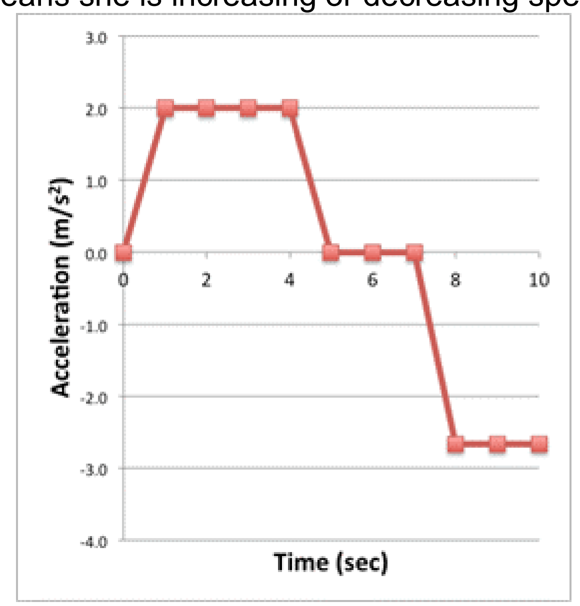
- http://go.uen.org/b3S

What does the slope of a velocity vs. time graph represent?

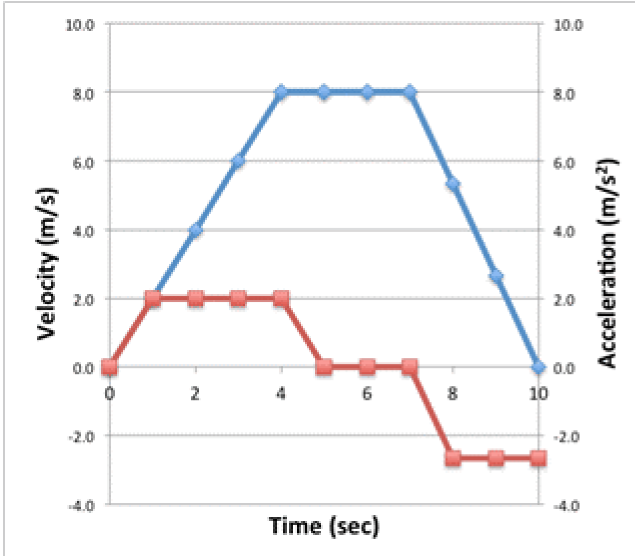
In a previous section, we discussed graphing velocity vs. time by looking at a graph of the velocity of a sprinter. The velocity time graph clearly shows positive or negative acceleration. We learned if the velocity versus time graph shows a positive slope then there is positive acceleration. If the slope is negative then there is negative acceleration. When the slope is zero there is no acceleration and velocity is constant (the speed nor the direction is changing).



The graph of acceleration versus time of the sprinter's motion appears different than the velocity versus, time graph. A positive slope on an acceleration versus time graph shows an increase in acceleration or the sprinter is increasing the rate of speeding up. A negative slope on the graph shows a negative acceleration over time or the sprinter is increasing the rate of slowing down. A slope of 0 shows that there is a constant increase or decrease of speed depending on if the value is positive or negative. For the sprinter a slope of 0 means she is increasing or decreasing speed at a constant rate.



A graph showing both at the same time helps to clearly see what is happening to velocity and speed over time.



Check Your Understanding

11. A race car traveling on a straight road starts from rest and increases its velocity to +60 m/s in 3 seconds. It then decreases its velocity to 40 m/s for the next second and maintains that velocity for the next second (see the data table below for its velocity). Complete the table filling in the acceleration for each second of the race car's movement and then graph both velocity and acceleration over time.

Time (s)	Velocity (m/s)	Acceleration (m/s^2)
0	0	
1	20	
2	40	
3	60	
4	40	
5	40	

Answers to "Check your Understanding"

1. If the brakes are applied while moving forward, then the acceleration is to negative (backward). If the brakes are applied while the car is traveling backward, then the acceleration is positive (forward).

2. Increase your speed in the negative direction (this could be west, south, down, backwards, left, etc.), making your velocity become more negative.

3. The velocity vector is directed north and the acceleration vector is directed south.

4. Using the given conversion, 65 km/hr = 18 m/s, and the acceleration is

$$a=\frac{\Delta v}{\Delta t}=\frac{18\text{m/s}}{4\text{s}}=4.5\text{m/s}^2$$

5. Using our conversion from before, 1 km/hr = 0.2778 m/s, we can make a conversion from km/hr to m/s.

$$40\text{ km/hr}\,\frac{0.2778\text{ m/s}}{1\text{ km/hr}}=11\text{m/s}$$

6. Yes, a car driving forward and slowing down would have a positive velocity and a negative acceleration.

7. Yes, a car moving forward at a constant velocity would have a positive velocity and a zero acceleration.

8. Yes, if a car is currently at rest, but speeding up it has a zero velocity and a positive acceleration. This could happen if the car is changing direction from backwards to forward and momentarily stops in order to change direction.

If the gazelle started from rest, and accelerates at 4.5m/s^2, then after the first second its speed is 4.5 m/s, after the second, its speed is 9.0 m/s, and after the third second its speed is 13.5 m/s. So we know the answer must be between 2 and 3 seconds. Using the definition of acceleration, $a=\frac{\Delta v}{\Delta t}$; substitution gives: $4.5\text{m/s}^2=\frac{11.5\text{m/s}}{\Delta t}$. Rearranging and solving for Δt, gives:

$$\Delta t=\frac{\Delta v}{a}=\frac{11.5\text{m/s}}{4.5\text{m/s}^2}=2.4\text{s}$$

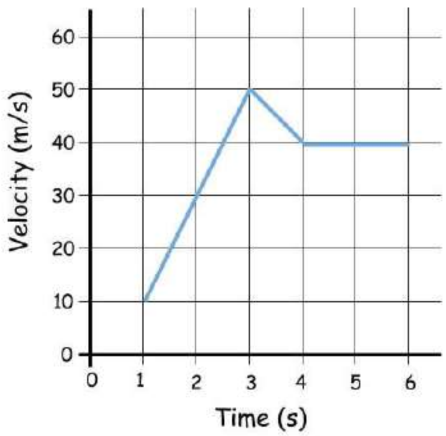
9 The slope of a velocity versus time graph represents the acceleration of an object.

10. The positive slope on a velocity-time graph shows positive acceleration. A slope of zero on a velocity-time graph shows no acceleration and constant speed. A negative slope shows negative acceleration, which can be slowing down.

11. Looking at the graph, she reaches double the velocity at 2 seconds. Her acceleration would be

$$a=\frac{\Delta v}{\Delta t}=\frac{4m/s-2m/s}{2s-1s}=2m/s^2$$

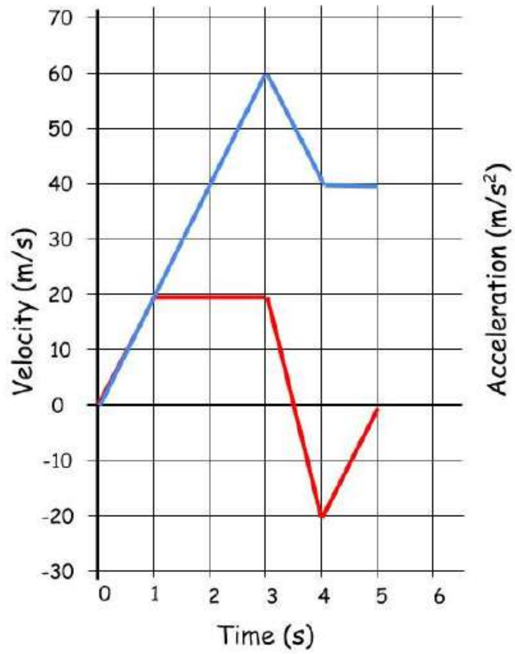
12.



13. If the brakes are applied while moving forward, then the acceleration is to negative (backward). If the brakes are applied while the car is traveling backward, then the acceleration is positive (forward).

Time (s)	Velocity (m/s)	Acceleration m/s^2
0	0	0
1	20	20
2	40	20
3	60	20
4	40	-20
5	40	0

Graph: The top line represents the velocity and the bottom line represents the acceleration.



1.3 Frame of Reference

Objectives

- Compare the motion of an object relative to two **frames of reference.**
- Predict the motion of an object relative to a different frame of reference (e.g., an object dropped from a moving vehicle observed from the vehicle and by a person standing on the sidewalk).
- Describe how selecting a specific frame of reference can simplify the description of the motion of an object.

How does a different frame of reference change the observed motion of an object?

The wings of this hummingbird are moving so fast that they're just a blur of motion. You can probably think of many other examples of things in motion. If you can't, just look around you. It's likely that you'll see something moving, and if nothing else, your eyes will be moving. So you know from experience what motion is. No doubt it seems like a fairly simple concept. However, when you read this article, you'll find out that it's not quite as simple as it seems.

Defining Motion

In science, motion is defined as a change in position. An object's position is its location. Besides the wings of the hummingbird in the opening image, you can see other examples of motion in the figures below. In each case, the position of something is changing.

Q: In each picture in the Figure above, what is moving and how is its position changing?

A: The train and all its passengers are speeding straight down a track to the next station. The man and his bike are moving along a road. The inchworm is slowly inching its way along a branch. The meteor is shooting through the atmosphere.

Frame of Reference

There is more to motion than objects simply changing position. You'll see why when you consider the following example. Assume that the school bus pictured in the figure below passes by you as you stand on the sidewalk. It's obvious to you that the bus is moving, but what about to the children inside the bus? The bus isn't moving relative to them, and if they look at the other children sitting on the bus, they won't appear to be moving either. If the ride is really smooth, the children may only be able to tell that the bus is moving by looking out the window and seeing you and the trees passing by.

This example shows that how we perceive motion depends on our frame of reference. **Frame of reference** refers to something that is not moving with respect to an observer that can be used to detect motion. For the children on the bus, if they use other children riding the bus as their frame of reference, they do not appear to be moving. But if they use objects outside the bus as their frame of reference, they can tell they are moving.

The video at the URL below illustrates other examples of how frame of reference is related to motion.

- http://go.uen.org/b3n

Q: What is your frame of reference if you are standing on the sidewalk and see the bus go by? How can you tell that the bus is moving?

A: Your frame of reference might be "stationary on the street", the same frame of reference as the trees and other stationary objects across the street. As the bus goes by, it is moving toward or away from stationary objects, and this helps you detect the bus's motion.

How can motion be predicted in different frames of reference?

Inertial Frames

There are endless examples of relative motion. Suppose that you're in an elevator that is rising with a constant speed of 2 m/s relative to the ground. If you release a ball while in this reference frame, how will the motion of the ball differ than had you dropped the ball while standing on the ground?

Had you been asleep in this reference frame and woke after the compartment was in motion, you would have no idea whatsoever you were in motion. There is no experiment that can be performed to detect constant velocity motion. In a closed compartment, people can feel acceleration but not constant velocity. If you've ever traveled in a jet moving 1000 km/hr (about 600 mi/hr) with no air turbulence, then you may know from firsthand experience that you cannot detect the forward motion of the plane - you don't feel like you are traveling 1000 km/hr. After the brief acceleration period in the elevator, you can no longer sense the motion of the elevator.

As a general statement, we consider all constant velocity reference frames to be equivalent. This idea is known as The Galilean Principle of Relativity. Constant-velocity reference frames are called inertial frames of reference. An "at-rest" reference frame is an arbitrary construct. If you're traveling with a constant velocity in your car, the

reference frame of the car is an at-rest frame. If you are in an elevator moving at 2 m/s, you are in an at-rest frame with respect to the compartment. And, you sitting and reading this firmly placed on the earth consider yourself to be in an at-rest reference frame. But you know the Earth itself is in motion. It rotates about its axis with a speed of about 1600 km/h (1000 mi/hr) at the equator, and it orbits the sun with an average speed of 108,000 km/h (67,000 mi/hr). In fact, the earth isn't even an inertial frame of reference since it rotates about its axis and its orbital speed varies.

(Remember, velocity is constant only if its magnitude and direction do not change—objects in circular motion do not qualify!) We usually approximate the earth as an inertial frame of reference since we do not readily sense the earth's rotation (angular acceleration).

NOTE: Objects on the Earth's surface have a maximum acceleration due to its rotation of about $0.03 m/s^2$—which we don't typically concern ourselves with since the acceleration due to gravity is $9.8 m/s^2$.

Relative Motion

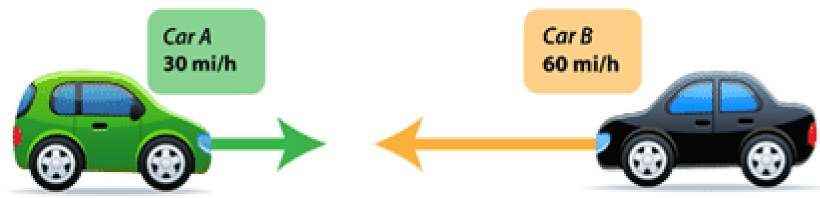
In the figure below, a moving walkway provides us with an example of relative motion. Let us consider two Cartesian coordinate systems. One is attached to the "stationary" earth. The other is attached to a walkway moving with a constant horizontal velocity of 1 m/s with respect to the earth. If a ball is thrown with an initial horizontal velocity of 3 m/s in the direction the walkway is moving by a person standing on the walkway, what horizontal velocity does a person standing on the ground measure for the ball? The person in the earth frame sees the ball having a combined velocity of 4 m/s. The person in the "moving frame" will measure it as 3 m/s. According to The Principle of Galilean Relativity, the velocity, v, seen from the at-rest frame is additive, that is, $v=1m/s+3m/s$. See the figure below.

This link shows relative motion on a subway:

- http://go.uen.org/b3o

Check Your Understanding

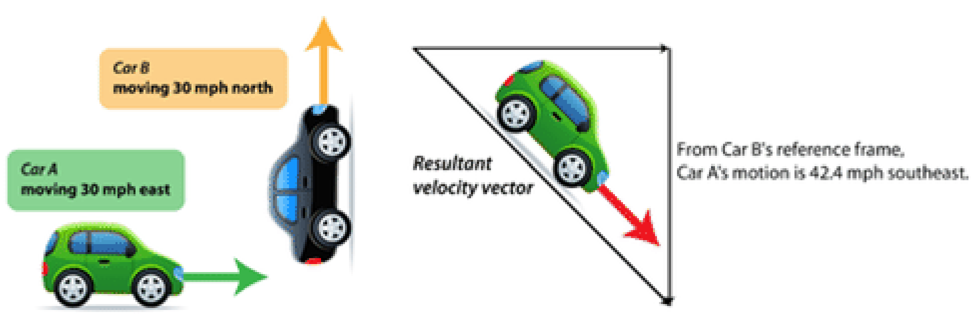
- Two cars are headed toward each other: Car A moves with a velocity of 30 mi/hr due east and Car B with a velocity of 60 mi/hr due west, relative to “at-rest” earth. We define motion to the east as positive, and motion to the west as negative. See the figure below.



1. What is the velocity of car B relative to car A? This means that we are assuming car A is our “at rest” coordinate system.

2. What is the velocity of car A relative to the velocity of car B? This means we are assuming car B is our “at rest” coordinate system.

- Car A is moving due east with a speed of 30 mi/hr and Car B is moving due north with a speed of 30 mi/hr.



3. What is the velocity of car A relative to car B?

4. What is the velocity of car B relative to car A?

How can selecting a different frame of reference simplify the description of motion?

Velocity is always measured relative to something. We measure how fast a person runs or how fast a car drives relative to the ground. However, we know from astronomy that the Earth itself is both turning around its axis and going around the Sun. As we've discussed before, a reference frame is a fixed point and directions from it that we measure relative to.

If you are on a bus going north at 60 mi/hr, then the person seated across the aisle from you has velocity 60 mi/hr north relative to the ground and velocity zero relative to you. If the bus is going at a steady velocity, you can toss a coin across to him, and it works the same as if you were standing on the earth. In the bus frame of reference, you and the other passenger have velocity zero, and the tossed coin has a slight velocity east (say 20 mi/hr). In this frame of reference, someone standing to the side of the road would have a velocity 60 mi/hr south.

In the "ground" frame of reference, you and the other passenger are both moving 60 mi/hr north, while the coin is moving diagonally northeast. The coin's velocity vector is 60 mi/hr north and 20 mi/hr east added together.

Both of these frames of reference are correct. You can solve any problems using either one, as long as you use it consistently. Some problems, though, are easier in one frame of reference than in another. If you wanted to solve how long it would take for the coin to go across the aisle, then the bus frame of reference is much simpler.

Answers to Check Your Understanding

1. From our previous statements regarding relative velocity we can "feel" that the relative velocity is greater than either speed: If we define the relative velocity (the velocity of car B relative to the velocity of car A) $v_{ba}=v_b-v_a$*, then -60mi/hr-30mi/hr=-90mi/hr, a person in car A sees car B moving* <u>*west*</u> *at 90 mi/hr. The person in car A sees himself as "motionless" while car B is moving toward him with car B's speed and his own speed which he does not perceive.*

2. $v_{ab}=v_a-v_b$*=30mi/hr - (-60mi/hr)=+90mi/hr.. A person in car B sees car A moving* <u>*east*</u> *at 90 mi/hr.*

3. v_{ab}*=42.4mi/hr* and 315° from the +x axis.

The two vectors are not along the same line so we'll use their components: v_a*=(+30,0)m/s* and v_b*=(0,+30)m/s* where east is +x and north is +y. Therefore v_a-v_b*=(30-0, 0-30)=(30,-30)*. The components are directed east and south, so the direction is southeast.

Since both components have the same magnitude, the angle must be 45°. Since the vector is in the southeast direction it is in the 4th Quadrant so the angle is 315°, and the magnitude is the Pythagorean sum 302+(-30)2=42.4 mi/hr.

4. The magnitude of the relative speed are the same. $|V_{ab}|=|V_{ba}|$ and 135° from the +x axis.

1.4 Newton’s First Law of Motion

Objectives

- Describe the motion of a stationary object on which balanced forces are acting.
- Describe the motion of a moving object on which balanced forces are acting.
- Describe the balanced forces acting on a moving object commonly encountered (e.g., forces acting on an automobile moving at constant velocity, forces that maintain a body in an upright position while walking).

What is Inertia?

Newton’s First Law of motion is about inertia; the law states, an object at rest will remain at rest and an object in motion will remain in motion, at a constant speed, in a constant direction until acted on by an unbalanced force. Prior to Newton and Galileo, the prevailing view on motion was still Aristotle's. According to Aristotle’s theory the natural state of things is at rest; force is required to keep something moving at a constant rate. This made sense to people throughout history because on earth, friction and air resistance slow moving objects to a stop. When there is no friction, a situation approximated in space, Newton's first law is much more evident.

Inertia is the property of an object that resists a change in its state of motion. An object’s inertia is related to the mass of the object. The more massive an object is, the more difficult it is to start it moving or to change its speed or direction once it is moving.

Mass and Weight

Mass and weight are two different things. Mass (typically in units of kg or grams) is a measure of the amount of matter in an object. Mass is related to the weight of an object, but mass and weight are not same thing. Weight is the measure of how much the force of gravity is pulling on the mass. When an astronaut travels to space, their mass is the same as when the astronaut was on Earth, but their weight has decreased because the force of gravity from the earth has decreased.

Watch this Explanation about Newton’s First Law of Motion here:
- http://go.uen.org/b3p

Simulation

Try the following simulation to apply these principles.
- http://go.uen.org/b3q
- http://go.uen.org/b3r

Check Your Understanding

1. When hit from behind in a car crash, a passenger can suffer a neck injury called whiplash. Use Newton's First Law to explain how this occurs and how headrests can prevent the injury.

2. A bobcat can outrun a rabbit in a short straight race, but the rabbit can escape with its life by zigzagging. The bobcat is more massive than the rabbit – explain how this strategy works.

3. After washing your hands, you find that there is no towel to dry your hands with, so you shake your hands dry. Using Newton's First Law, explain why this is effective.

Answers to Check Your Understanding

1. The passenger's head will remain at rest for the split second when the seat exerts a big force on the passenger's back causing a "whiplash" on your neck. This is an example of newton's first law because your head is not acted on by an unbalanced force while the rest of your body is. A headrest causes your head to accelerate with the rest of your body.

2. The bobcat must exert a bigger force to change directions than the rabbit because the bobcat has more inertia. This extra force needed for the bobcat to change directions allows the rabbit to get away.

3. As you initially move your hands, the water moves with your hands. Then, you suddenly stop your hands. Because of Newton's First Law of Motion, the water continues to move forward and slides off your hands.

Chapter 1 Summary

Vocabulary

- Acceleration: a change in velocity, divided by change in time.
- Average Velocity: displacement divided by time in which the displacement occurred.
- Balanced Forces: when the net sum off all of the forces acting on a body equals zero.
- Displacement: the difference between final and initial positions.
- Distance: a scalar quantity giving the positive length between two points frame of reference.
- Frame of reference: refers to something that is not moving with respect to an observer that can be used to detect motion. Describes the coordinate system of a problem. Instantaneous Velocity: the velocity at a specific time.
- Position: location of an object.
- Rate: change in a measurement of units with respect to the change in another measurement (which is typically time)
- Scalar: a description of motion referring only to magnitude.
- Speed: Total distance traveled divided by total travel time.
- Time: measurement of a period in which something occurred, is occurring, or will occur.
- Vector: a description of motion referring to both magnitude and direction (e.g. displacement, velocity).
- Velocity: Change in position divided by change in time.

Summary

- The motion of an object can be described by measurements of its position at different times.
- Velocity is a measurement of the rate of change of position of an object over time.
- Acceleration is a measure of the rate of change of velocity of an object over time. Change in velocity may be due to the change in speed and/or the change in direction.
- Motion is defined relative to the frame of reference from which it is observed.
- An object's state of motion will remain constant unless unbalanced forces act upon the object. This is Newton's First Law of Motion.

Online Interactive Activities

The Moving Man: http://go.uen.org/b3s (This link requires JAVA)

CHAPTER 2

Standard 2: Force Mass and Acceleration

Chapter Outline

Standard 2: Students will understand the relation between force, mass, and acceleration.

Objective 1: Analyze forces acting on an object.

a. Observe and describe forces encountered in everyday life (e.g., braking of an automobile - friction, falling rain drops - gravity, directional compass - magnetic, bathroom scale - elastic or spring).

b. Use vector diagrams to represent the forces acting on an object.

c. Measure the forces on an object using appropriate tools.

d. Calculate the net force acting on an object.

Objective 2: Using Newton's second law, relate the force, mass, and acceleration of an object.

a. Determine the relationship between the net force on an object and the object's acceleration.

b. Relate the effect of an object's mass to its acceleration when an unbalanced force is applied.

c. Determine the relationship between force, mass, and acceleration from experimental data and compare the results to Newton's second law.

d. Predict the combined effect of multiple forces (e.g., friction, gravity, and normal forces) on an object's motion.

Objective 3: Explain that forces act in pairs as described by Newton's third law.

a. Identify pairs of forces (e.g., action-reaction, equal and opposite) acting between two objects (e.g., two electric charges, a book and the table it rests upon, a person and a rope being pulled).

b. Determine the magnitude and direction of the acting force when magnitude and direction of the reacting force is known.

c. Provide examples of practical applications of Newton's third law (e.g., forces on a retaining wall, rockets, walking).

d. Relate the historical development of Newton's laws of motion to our current understanding of the nature of science (e.g., based upon previous knowledge, empirical evidence, replicable observations, development of scientific law).

2.1 What is Force?

Objectives

- Observe and describe **forces** encountered in everyday life (e.g., braking of an automobile - friction, falling rain drops - gravity, directional compass - magnetic, bathroom scale - elastic or spring).
- Use **vector** diagrams to represent the forces acting on an object.
- Measure the **forces** on an object using appropriate tools.
- Calculate the **net force** acting on an object.

What are different types of forces?

Force

Carson has been riding a scooter for almost as long as he can remember. As you can see, he's really good at it. He can even do tricks in the air. It takes a lot of practice to be able to control a scooter like this. Carson automatically applies just the right forces to control his scooter.

Defining Force

Force can be simply defined as a push or pull. There are four fundamental forces in the universe, including the force of gravity, electromagnetic force, and weak and strong nuclear forces. When it comes to the motion of everyday objects, however, the forces of interest include mainly gravity, friction, and applied forces. An applied force is any force that a person or thing applies directly to an object that it is in contact with. Other forces that act on objects include thrust (used to propel rockets), air resistance (which slows down objects in air), tension (the force on a rope or string), spring force (the force exerted by a spring or elastic), and the normal force (the force that acts perpendicularly to a surface). See section 7.1 for more information about common forces.

Q: What forces act on Carson's scooter?

A: Gravity, friction, and applied forces all act on Carson's scooter. Gravity keeps pulling both Carson and the scooter toward the ground. Friction between the wheels of the scooter and the ground prevent the scooter from sliding but also slow it down. In addition, Carson applies forces to his scooter to control its speed and direction.

Force and Motion

All changes in motion are caused by forces. Every time the motion of an object changes, it's because a force has been applied to it. Force can cause a stationary object to start moving or a moving object to change its speed or direction or both. A change in the speed or direction of an object is called acceleration. Remember that acceleration happens when there is a change in the velocity. Since velocity includes speed and direction, changing either speed or direction changes the velocity of an object. Look at Carson's little brother Colton in the Figure below. He's getting his scooter started by pushing off with his foot. The force he applies to the ground with his foot causes the scooter to move in the opposite direction. The harder he pushes against the ground, the faster the scooter will go.

What are Newton's Laws of Motion?

Isaac Newton stated the relationship between force, mass and acceleration in his comprehensive treatise called the Principia. He organized this particular idea into three laws of motion. A modern translation would be something like this:

Newton's first law of motion – an object at rest will remain at rest and an object in motion will remain in motion, at a constant speed, in a constant direction until acted on by an outside force.

Newton's second law of motion – a net force will produce an acceleration that is proportional to the force and inversely proportional to the mass being accelerated. In simpler words, net force equals mass times acceleration. Just remember the equation F_{Net}=ma.

Newton's third law of motion – for every action there's an equal and opposite reaction. This idea means that forces always come in pairs. If there is one force there are two. These force are equal in magnitude and opposite in direction.

How much an object accelerates when a force is applied to it depends not only on the strength of the force but also on the object's mass. For example, a heavier scooter would be harder to accelerate. Colton would have to push with more force to start it moving and move it faster.

You can explore the how force, mass, and acceleration are related by doing the activity at this URL:

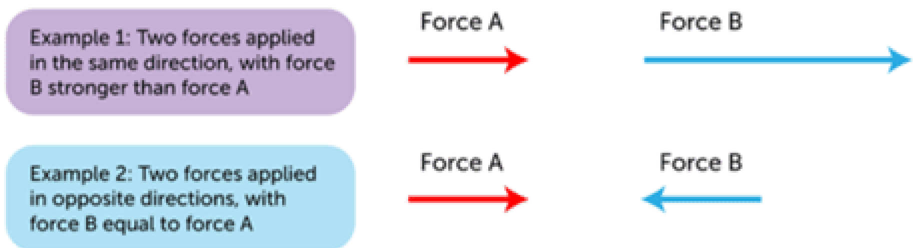
- http://go.uen.org/b3t

Q: What units do you think are used to measure force?

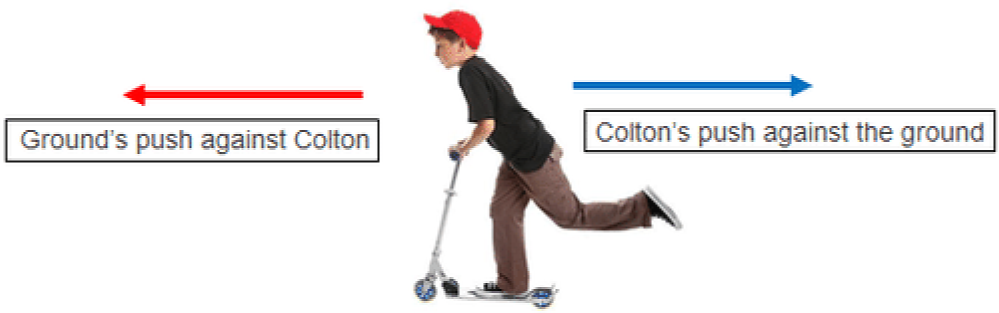
A: The SI unit for force is the Newton (N). A Newton is the force needed to cause a mass of 1 kilogram to accelerate at $1\ m/s^2$ so a Newton equals $1\ kgm^2/s^2$. The Newton was named for the scientist Sir Isaac Newton, who is famous for his laws of motion and gravity.

Force as a Vector

Force is a vector, or a measure that has both size and direction. For example, Colton pushes on the ground in the opposite direction that the scooter moves, so that's the direction of the force he applies. He can give the scooter a strong push or a weak push. That's the size of the force. Like other vectors, a force can be represented with an arrow. You can see some examples in the figure below. The length of each arrow represents the strength of the force, and the way the arrow points represents the direction of the force.



Example: Colton pushes against the ground behind him. The ground pushes back with equal force to the left, causing the scooter to move in that direction. Force arrows A and B in example 2 above could represent these forces.



2.2 What is Newton's 2nd Law of Motion?

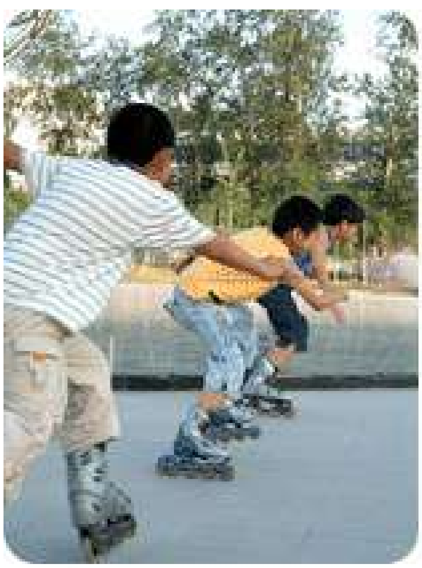
Objectives

- Determine the relationship between the net force on an object and the object's acceleration.
- Relate the effect of an object's mass to its acceleration when an unbalanced force is applied.
- Determine the relationship between force, mass, and acceleration from experimental data and compare the results to Newton's second law.
- Predict the combined effect of multiple forces (e.g., friction, gravity, and normal forces) on an object's motion.

What is the relationship between force, mass, and acceleration?

Key Equation

Net Force = mass x acceleration $F_{Net} = ma$



These boys are racing around the track at Newton's Skate Park. The boy who can increase his speed the most will win the race. Tony, who is closest to the camera in this picture, is bigger and stronger than the other two boys, so he can apply greater force to his skates.

Q: Does this mean that Tony will win the race?

A: Not necessarily, because force isn't the only factor that affects acceleration. Mass also needs to be taken into consideration.

Force, Mass, and Acceleration

An object accelerates whenever it speeds up, slows down, or changes direction. Remember any change in directions is acceleration even if the speed remains constant. Acceleration occurs whenever an unbalanced force acts on an object. Two factors affect the acceleration of an object: the net force acting on the object and the object's mass. Newton's second law of motion describes how force and mass affect acceleration. The law states that the acceleration of an object equals the net force acting on the object divided by the object's mass. This can be represented by the equation:

$$\text{acceleration} = \frac{\text{Net Force}}{\text{mass}} \quad \textbf{or} \quad a = \frac{F_{Net}}{m}$$

This is commonly rearranged and written as

$$F_{Net} = ma$$

Tony exerts a backward force against the ground, as you can see in the Figure below, first with one skate and then with the other. This force pushes him forward. Although friction partly counters the forward motion of the skates, it is weaker than the force Tony exerts. Therefore, there is a forward net force on the skates.

Direct and Inverse Relationships

Newton's second law shows that there is a direct relationship between force and acceleration. The greater the force that is applied to an object of a given mass, the more the object will accelerate. For example, doubling the force on the object doubles its acceleration.

The relationship between mass and acceleration is different. It is an inverse relationship. In an inverse relationship, when one variable increases, the other variable decreases. The greater the mass of an object, the less it will accelerate when a constant force is applied. For example, doubling the mass of an object results in only half as much acceleration for the same amount of force.

Check Your Understanding

1. State Newton's second law of motion.

2. How can Newton's second law of motion be represented with an equation?

3. If the net force acting on an object doubles and the mass remains unchanged, how will the object's acceleration be affected?

4. Tony has a mass of 50 kg, and his friend Sam has a mass of 45 kg. Assume that both friends push off on their rollerblades with the same force. Explain which boy will have greater acceleration.

5. Tony has greater mass than the other two boys he is racing above. How will this affect his acceleration around the track?

Answers to Check Your Understanding

1. The acceleration of an object is directly proportional to the force acting on the object and inversely proportional to the mass of the object.

2. $\Sigma F = F_{Net} = ma$

3. Because of $\Sigma F=ma$ if the force doubles and the mass remains the same then the acceleration must double.

4. If we rearrange $\Sigma F=ma$ to $a = \frac{F_{Net}}{m}$, then we can see that if the forces are equal but the mass of one object is greater than the other than the object with the object with the least mass will have the greatest acceleration. So Sam will have the greatest acceleration.

5. Tony's greater mass will result in less acceleration for the same amount of force.

2.3 What is Newton's 3rd Law of Motion?

Objectives

- Identify pairs of forces (e.g., action-reaction, equal and opposite) acting between two objects (e.g., two electric charges, a book and the table it rests upon, a person and a rope being pulled).
- Determine the magnitude and direction of the acting force when magnitude and direction of the reacting force is known.
- Provide examples of practical applications of Newton's third law (e.g., forces on a retaining wall, rockets, walking).
- Relate the historical development of Newton's laws of motion to our current understanding of the nature of science (e.g., based upon previous knowledge, empirical evidence, replicable observations, development of scientific law).

What are action/reaction pairs?

It was Newton who realized singular forces could not exist: they must come in pairs. In order for there to be an "interaction" there must be at least two objects, each "feeling" the other's effect. Newton's Third Law states: Whenever two objects interact they must necessarily place equal and opposite forces upon each other.

Mathematically, Newton's Third law is expressed as: $\boldsymbol{F_{AB}} = -\boldsymbol{F_{BA}}$, where the subscript "AB" means, the force exerted on A by B and the subscript "BA" means, the force exerted on B by A. Forces $\boldsymbol{F_{AB}}$ and $\boldsymbol{F_{BA}}$ have the same magnitude but never act upon the same object. A Newton's Third Law pair of forces never acts upon the same object. For example, a force pair for a book sitting on a table would be $\boldsymbol{F_{AB}}$ is the force that the book exerts on the table while $\boldsymbol{F_{BA}}$ is the force that the table exerts on the book. One force acts on the table and one force acts on the book (different objects). Forces that are equal and opposite and do act upon the same object are not considered a force pair. For example, if two forces both act on the book (such as the table pushes on the book and my hand pushes on the book), those forces cannot be called force pairs.

Problem Solving

We use Newton's laws to solve "dynamics" problems. Dynamics, unlike kinematics, considers the forces acting upon objects. Whether it is a system of stars gravitationally bound together or two colliding automobiles, we can use Newton's laws to analyze and quantify their motion. Of Newton's three laws, the major mathematical "workhorse" used to investigate these and endless other physical situations is Newton's Second Law:

$$\Sigma F = F_{Net} = ma$$

(Note: ΣF means the sum of the forces or the net force.)

In using Newton’s laws we assume that the acceleration is constant in all of the examples in the present chapter. Newton’s laws can certainly deal with situations where the acceleration is not constant, but, for most part, such situations are beyond the level of this book. As a last simplification, we assume that all forces act upon the center of mass of an object. The center of mass of an object can be thought of as that point where all of the mass of an object is concentrated. It is the point at which if your finger were placed the object would remain balanced, at the 50cm point of a meter stick for example.

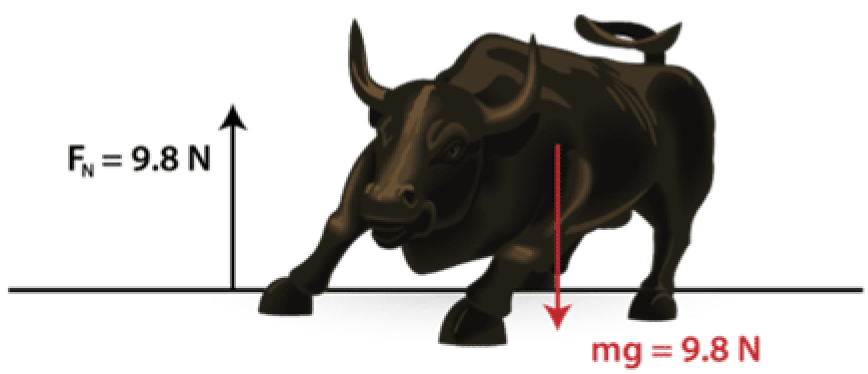
How are Vector Diagrams drawn?

Vector Diagrams

A diagram showing those forces that act upon a body is called a Vector Diagram. The forces in a Vector Diagram show the direction each force acts, and, when possible, the relative magnitude of the each force by the length of the force vector. Each force in a Vector Diagram must be labeled appropriately so it is clear what each arrow represents. A Free-Body Diagram is similar to a Vector Diagram. See Section 7.1 for more information on Free-Body Diagrams.

Example 1: Sitting Bull

In the figure below, a 1.0 kg bull statue is resting on a mantelpiece. Analyze the forces acting on the bull and their relationship to each other.



There are two vertical forces that act upon the bull: The earth pulling down on the center of mass of the bull with a force of $W=mg=1.0kg \times 9.8m/s^2 = 9.8N$ and the floor pushing back against the weight of the bull, with a “normal” force FN. The term “normal” force comes from mathematics where normal means perpendicular to a surface. The normal force vector (often stated as “the normal”) is drawn perpendicular to the surface that the

bull rests upon. Normal forces are usually associated with a push upon an object not a pull and always require a surface to be present.

Using Newton's Second Law we write:

$$\Sigma F = F_N - mg$$
$$= ma = 0\text{ N}$$

The negative sign (−mg) indicates that the earth pulls downward on the statue. Since the bull is at stationary, its acceleration is zero and, therefore, the net force is also zero. Usually, when solving problems with Newton's Second Law, forces that point down and to the left are expressed negatively and forces that point up and to the right are expressed positively. These are just conventions and any consistent set of conventions is permissible. It is also important (when enough information is provided) to draw the length of a vector in proportion to its magnitude. In the diagram above, F_N and mg are drawn the same length, reflecting the fact that they have the same magnitude. Important: in the diagrams, the arrows must originate inside the object, pointing "outward".

The statue is stationary so it has zero acceleration. This reduces the problem to $W=mg=F_N$, which intuitively seems reasonable. When the problem is solved, it shows the magnitudes of the forces are equal. It must be kept in mind that their directions are opposite, but they are not a force pair since the normal force and the weight force act on the same object.

Example 2: Hanging Loose

In the diagram below Mr. Joe Loose is holding onto a rope. Joe's mass is 75 kg. Use $g=9.8\text{ m/s}^2$.

a. Draw Joe's Vector Diagram.

Answer

A tension force is transmitted through a string, cord or rope. The convention in physics is to use label T, for "tension".

Once again, we apply: F = ma, where F = T - mg = ma = 0 N, since a = 0 m/s^2.

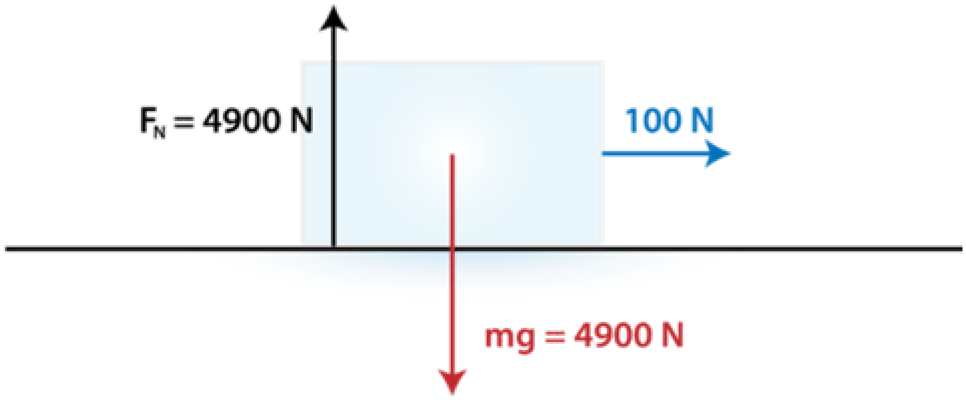
b. What is the tension in the rope?

Answer: We assume the mass of the rope is negligible. Including the mass of the rope is not particularly difficult, but we're just starting out!

Example 3: Sliding Away

A 4900 N block of ice, initially at rest on a frictionless horizontal surface, has a horizontal force of 100 N applied to it.

a. Draw a Vector diagram of the problem.



Typically, applied forces are written as F. If there are multiple forces, depending on the wording of the problem, each force may have a subscript that reflects its meaning or just be numbered.

Questions:

1. Find the mass of the block of ice in the figure above, using g = 9.8m/s^2.

Answer: The mass of the block is 500 kg.

2. Find the acceleration of the block of ice in the figure above.

Answer:

$$a = \frac{F}{m} = \frac{100\text{ N}}{500\text{ kg}} = 0.20\text{ m/s}^2$$

3. Find the velocity of the block at t = 100 sec.

Answer: $a = \frac{\Delta v}{\Delta t}$ and solving for velocity gives

$$\Delta v = v_f - v_i = a\Delta t$$

$$v_f - 0\text{m/s} = 0.20\text{m/s}^2 \times 100\text{s}$$

$$v_f = 20\text{m/s}$$

Example 4: A Touching Story

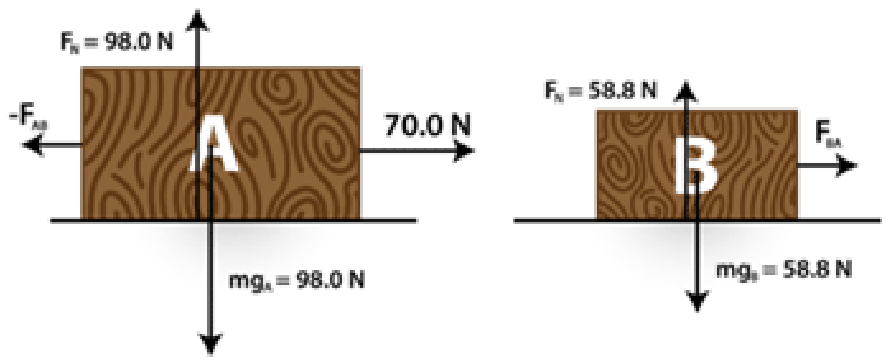
In the figure below Block A has a mass of 10.00 kg and Block B has a mass of 6.00 kg. Both blocks are in contact with each other, with Block A experiencing an applied 70.0 N force to the right as shown.

Note: Both blocks rest on a frictionless surface and have the same acceleration.

Note: When referring to more than one mass, we often use the word “system”.

a. Draw the Vector Diagrams for both Block A and Block B.

Answer:



As Block A moves to the right it experiences a force from Block B to the left. This force is labeled $-F_{AB}$ (force on A by B). Notice that block A also has the 70.0 N force to the right, the weight of the block, and the normal force acting on the block.

Block B is pushed to the right with the same force that it exerts upon Block A, according to Newton's Third Law. This force is labeled: F_{BA} (force on B by A); the magnitudes of $-F_{AB}$ and F_{BA} are equal, according to Newton's Third Law. Notice that block B does not have the 70.0 N force on it (that force wasn't directly acting on block B), but block B does have its own weight and its own normal force acting on it.

b. Find the acceleration of the system.

Answer: Both masses will have the same acceleration as was stated in the scenario. We will find the acceleration of the system using F = ma. Rearranging and substituting shows

$$a = \frac{F}{m}$$

$$a = \frac{70.0\ N}{16.00\ kg} = 4.375\ m/s^2$$

c. What is the magnitude of the force between Block A and Block B (F_{AB} or F_{BA})?

Answer: This is answered by finding the force necessary to accelerate block B at the rate of acceleration found previously. Since the net force on block B is same as F_{BA},

$F_{BA} = F_{Net} = ma = 6.00\ kg \times 4.375\ m/s^2 = 26.25\ N$

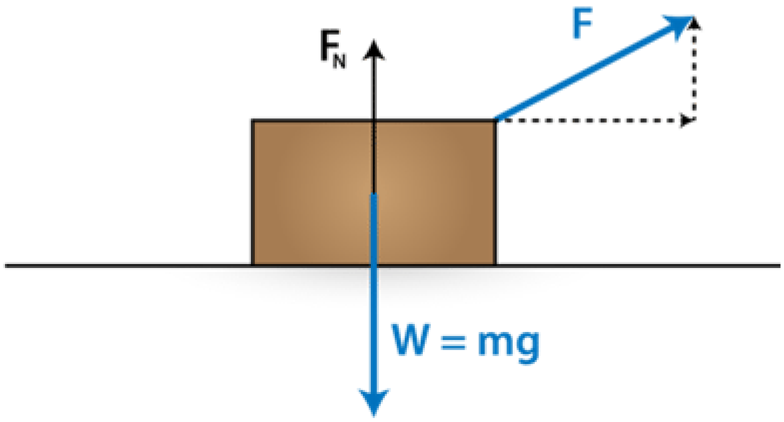
How is friction related to the normal force?

Introduction

Just as velocity and acceleration are vectors that can point in any direction, force is also a vector that has both a magnitude and a direction.

The Normal Force

A normal force is the force exerted by the ground or other object that prevents other objects from going through it. In the figure below, a block that rests upon the ground is pulled in a diagonal direction up and to the right. Just as velocity and acceleration can have x and y components, forces can have x and y components. We will need the same skills in resolving the force vector in the figure below.



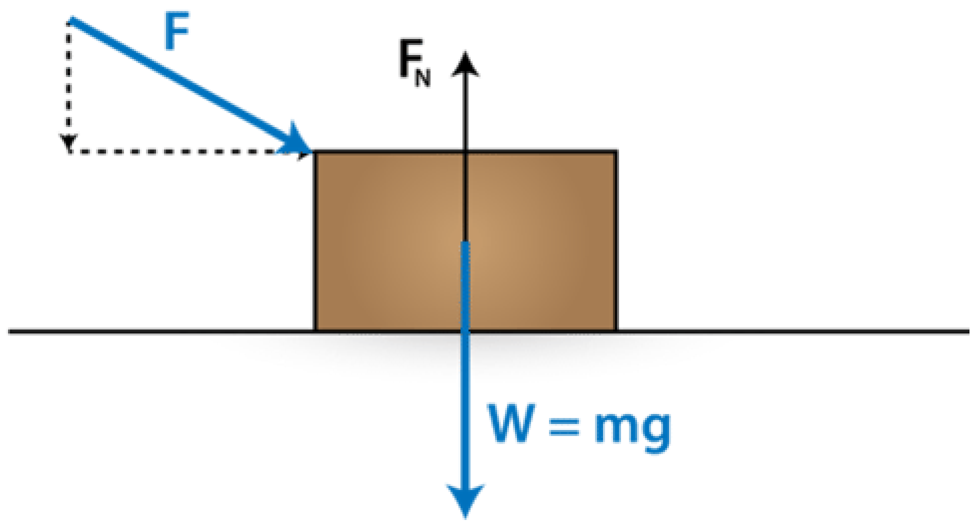
The applied force, F, acts at an angle to the horizontal. Knowing the value of the angle is not necessary to understand the effect on the normal force. Recall that the normal force, F_N, is the reaction force to the force that the block exerts on the ground. The applied force, F, has two components. One component acts toward the right (the x component) and the other component acts upward (the y component). Consider the effect that they component has on the normal force. Since they component of the force F acts in the upward direction it effectively "eases" some of the block's weight off the ground. If they component were equal in magnitude to the weight of the block, the ground would not experience any force upon it due to the weight of the block. We can see that upward forces reduce the reaction force on the block. Thus, upward forces acting on the block reduce the normal force.

Check Your Understanding

In the figure above, the weight, mg, of the block is 100 N and the force, F, has a y-component, F_y, of 25 N.

1. What normal force, F_N, does the ground exert upon the block if F_{net}= 0

2. Had the applied force been directed as shown in this diagram (see the figure below), what effect do you think it would have had on the normal force?



a. The normal force is greater than the weight of the block.

b. The normal force is less than the weight of the block.

c. The normal force equals the weight of the block.

What is the difference between kinetic and static friction?

Friction

Friction is a force that opposes two objects sliding against each other, and is a contact force like the normal force. While the normal force acts perpendicular to the flat surface, friction acts in a direction along the flat surface of an object. We generally speak of two kinds of friction: kinetic friction and static friction. We will begin our discussion of friction with kinetic friction.

Kinetic Friction

"Kinetic" means moving. Kinetic friction means friction between two objects sliding against each other, such as:

- Sliding a book across a desktop.
- Your foot slipping on an icy pavement. The force from kinetic friction is abbreviated f_k. (Friction forces by convention may use a lowercase f.)

We know a net force must exist on the book because it eventually stops moving. Newton's Second Law implies there must be some force acting on the book to slow it down and eventually bring it to rest. We call this force kinetic friction. Friction arises

because no matter how smooth the surface of the book may look or feel, or the surface it is in contact with, microscopically the two surfaces are rough. The smallest unevenness of the surfaces acts to impede the motion of the book. In fact, a force must be applied to the book just to overcome this "roughness" before it can be set into motion. The force that acts on the book before it is set into motion is called the static friction force, which we will discuss after dealing with kinetic friction.

We know that kinetic friction follows three basic rules:

1. The frictional force is independent of the relative velocity between the two surfaces for conventional speeds.

2. The frictional force is independent of contact surface area. If you slide a book lying flat or turn it on edge, the force of friction is the same.

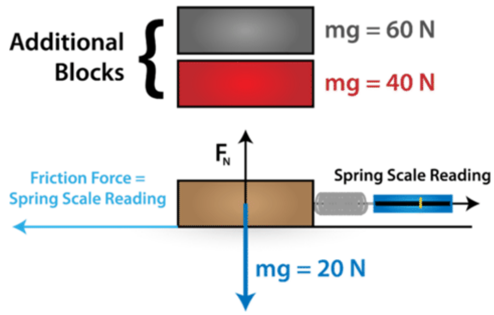
3. The frictional force, f_k, is directly proportional to the normal force the two objects press against each other with, F_N, and also directly proportional to the roughness or stickiness of the surface, called its coefficient of friction. We write this as $f_k = \mu_k F_N$ where μ_k is the coefficient of friction. The symbol, μ, is the Greek letter mu and pronounced "myoo" in English. The rougher or stickier the contact between two surfaces, the larger the value of μ_k. A frictionless surface would have $\mu_k=0$. (Notice that μ does NOT have units because it is just a ratio of forces, so the units all cancel out.)

As you well know, it's easier to push an object from one point to another than to carry it from one point to another. We usually just accept this observation as obvious. But why is this so?

The observation leads to the conclusion that the force of kinetic friction is usually less than the weight of the object to be moved. If not, why push when you could more easily lift?

The coefficients of friction, μ_k, are measured experimentally. A typical experimental set-up, which is often encountered in school physics laboratories, is to use a spring scale to pull increasing weights at a constant velocity, as shown in the figure below. Since the velocity is constant, the force that the spring scale exerts is equal to the magnitude of the kinetic friction. As the weight that is pulled increases, so too does the minimum force required to set the weight in motion. But as noted above, we would expect the force reading on the spring scale, to be smaller than the weight being pulled. The ratio of the force on the spring scale to the weight of the object is found to be constant, and is μk.

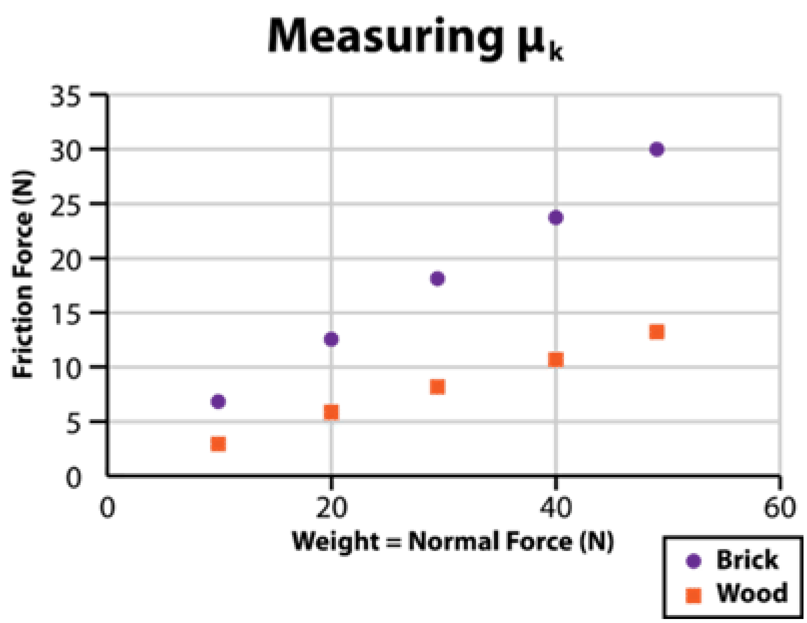
The set-up



Weight (N)	Spring reading = friction force (N)
20	10
40	20
60	30

If we graph kinetic friction force vs. weight, we would find a straight line with the slope of 0.5. The slope of this graph represents the coefficient of friction, μ_k. Notice that friction is measured in Newtons since it is a force.

The figure below shows two experiments measuring the coefficient of kinetic friction for brick and wood on polished oak.



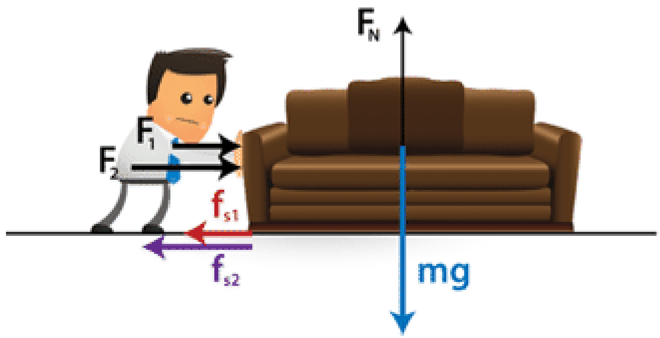
Static Friction

The original meaning of “static” is “not moving”. Static friction, f_s, exists when the contact surfaces do not slide relative to one another. Two examples would be:

1. A coin on an inclined surface that remains stationary.
2. Exerting a force on heavy couch that refuses to move.

For a given pair of surfaces, the coefficient of static friction, μ_s is larger than the coefficient of kinetic friction, μ_k. Put simply: There is less friction when objects are in motion. It is easier to keep moving an object than it is to start moving an object. We mentioned earlier in the section that regardless of how smooth the surfaces of two objects appear, at the microscopic level they are very rough. Atoms actually interact along the irregular contact areas between the surfaces forming electrical bonds. As soon as there is relative motion between the surfaces the bonds begin to break. Heat due to friction continues to aid in breaking the bonds, making it easier to maintain motion; hence kinetic friction is smaller than static friction; and $\mu_k < \mu_s$

Consider the following figure.



The man in the figure is trying to slide a heavy couch. He exerts a force F_1 that is insufficient to set the couch in motion; he then applies a greater force F_2 and the couch still does not move. In each case, since a force was placed upon the couch, and it remained stationary, an equal and opposite force must have acted upon the couch (f_{s1} and f_{s2} respectively) such that the net force on the couch remained zero, and the couch remained at rest. We call this force, static friction. But unlike kinetic friction, the static friction force is not confined to one value. For example, if F_1 was 100 N and F_2 was 150 N in Figure, then the static friction forces were $f_{s1}=100\ N$ and $f_{s2}=150\ N$, respectively. In fact, the static friction force can take on any value greater than or equal to zero up to the maximum force at which the couch is set into motion. At the point the couch is set into motion, static friction is gone and kinetic friction begins. Because static friction can take on any value up to the point of motion, we define static friction using an inequality:

$$F_s \leq \mu_s F_N$$

The coefficient of static friction, μ_s, is found by determining the maximum force, f_{smax}, just before the instant an object is set into motion. We will generally drop the subscript on the static friction force when the context is clear.

Example

The couch in the figure above just begins to move when a force of 175 N is applied to it.

1. What is the maximum static friction force, F_s, between the couch and the floor?
2. What is the coefficient of static friction, μ_s, if the couch weighs 1000 N?

Solutions:

1. Since the maximum force applied before the couch moves is 175 N this must be the maximum static friction; F_s=175 N.
2. $$\mu_s = \frac{F_s}{F_N} = \frac{175\text{ N}}{1000\text{ N}} = 0.175$$

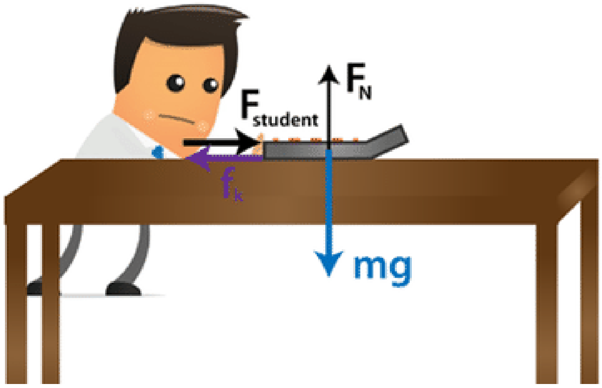
Notice that the coefficient of static friction, μ_s, is a pure number (it has no units) just as the coefficient of kinetic friction, μ_k. This is because the coefficient of static friction, s, depends upon the nature of the materials in contact and it is a ratio of two forces, as is the coefficient of kinetic friction, μ_k.

Kinetic and Static Friction Oppose Motion

Friction acts to oppose the motion caused by an applied force; thus opposing the relative motion between two surfaces. If you attempt to accelerate your car and there is insufficient static friction between the tires and the road (say, you're on ice), the tires would spin and the car would gain no additional speed. Kinetic friction would oppose the motion of the tires, even on ice, and you'd "burn rubber". However, during those moments when your tires made contact with the asphalt static friction would oppose the applied force your tires put upon the road and send the car forward. At the area of contact between the tire and the road, the tire pushes back on the pavement and the pavement pushes on the tire in the forward direction (Newton's 3rd law in action!). The force of static friction is responsible for pushing the car forward. The force of static friction opposes the motion of the tire relative to the road but has the same direction as the velocity of the car.

Check Your Understanding

- A student pushes on a calculator lying on a table with a horizontal force of 1 N but the calculator remains motionless.



3. What is the magnitude of the static friction force on the calculator?

4. Can the static friction force ever be smaller or larger than 1 N?

In this image, a tire weight is being pulled by a man with a rope tied around his waist.

4. If the man in the picture were taller, and he applied a force of the same magnitude to the weight, how would the normal force on the weight change?

Answers to Check Your Understanding

1. We know that weight and the normal force act only in the y direction, and that the block is not moving (velocity and acceleration are zero). We can use Newton's Third Law, which can be applied to the net force in the y direction and the acceleration in the y direction.

Therefore,

$$\Sigma F = F_N + F_y - F_g = 0$$

$$F_N = F_g - F_y$$
$$= 100\text{ N} - 25\text{ N}$$
$$= 75\text{ N}$$

2. a

$$\Sigma F = F_N - F_y - F_g = 0$$

$$\begin{aligned} F_N &= F_g + F_y \\ &= 100\ \text{N} + 25\ \text{N} \\ &= 125\ \text{N} \end{aligned}$$

3. a. Since the calculator remains stationary, the force of static friction and the force that the student exerts must be equal and opposite.

3. b. The static force can easily be smaller. Any force less than 1 N that the student exerts upon the calculator will be equal and opposite to the static friction force. The static friction can take on an infinite number of values below the threshold force that sets the calculator in motion. The static friction force may possibly be larger than 1 N if the student applies a bit more force and the calculator remains motionless. The force at which the calculator just begins to move is the maximum force that static friction can provide.

4. The taller he is, the more vertical is the force, so the normal force would decrease.

Chapter 2 Summary

Vocabulary

- Force: Any push or pull on an object.
- Friction: the rubbing of one body against another; while it often opposes motion that is not always the case.
- Gravity: the force that attracts a body toward the center of the earth, or toward any other physical body having mass.
- Net Force: The vector sum of the forces acting on an object. Also equal to the product of mass and acceleration of the object.
- Normal Force: A force that acts on an object perpendicular to the surface that it is on.

Summary

- Force is defined as a push or pull acting on an object.
- Forces include gravity, friction, tension, air resistance, and applied forces.
- Force causes changes in the speed or direction of motion. These changes are called acceleration.
- The SI unit for force is the Newton (N).
- Force is a vector because it has both size and direction. Like other vectors, it can be represented by an arrow.
- A Vector Diagram is a picture that shows the types and relative magnitudes of the force acting on an object.
- Newton's Second Law of Motion states that the acceleration of an object equals the net force acting on the object divided by the object's mass.
- According to Newton's Second Law, there is a direct relationship between force and acceleration and an inverse relationship between mass and acceleration.
- Newton's Third Law of Motion states that no force acts alone; every force has second force that is equal is magnitude and opposite in direction.

Online Interactive Activities

Force Interactive: http://go.uen.org/b3u

Force and Motion: Basics on PhET: http://go.uen.org/b3v

Free Body Diagram-calculating forces; including friction: http://go.uen.org/b3w

Friction on PhET: http://go.uen.org/b3x

CHAPTER 3

Standard III: Gravitational and Electric Forces

Chapter Outline

Standard 3: Students will understand the factors determining the strength of gravitational and electric forces.
Objective 1: Relate the strength of the gravitational force to the distance between two objects and the mass of the objects (i.e., Newton's law of universal gravitation).

a. Investigate how mass affects the gravitational force (e.g., spring scale, balance, or other method of finding a relationship between mass and the gravitational force).

b. Distinguish between mass and weight.

c. Describe how distance between objects affects the gravitational force (e.g., effect of gravitational forces of the moon and sun on objects on Earth).

d. Explain how evidence and inference are used to describe fundamental forces in nature, such as the gravitational force.

e. Research the importance of gravitational forces in the space program.

Objective 2: Describe the factors that affect the electric force (i.e., Coulomb's law).

a. Relate the types of charge to their effect on electric force (i.e., like charges repel, unlike charges attract).

b. Describe how the amount of charge affects the electric force.

c. Investigate the relationship of distance between charged objects and the strength of the electric force.

d. Research and report on electric forces in everyday applications found in both nature and technology (e.g., lightning, living organisms, batteries, copy machine, electrostatic precipitators).

3.1 Gravitational Force

Objectives

- Investigate how mass affects the gravitational force (e.g., spring scale, balance, or other method of finding a relationship between mass and the gravitational force).
- Distinguish between mass and weight.
- Describe how distance between objects affects the gravitational force (e.g., effect of gravitational forces of the moon and sun on objects on Earth).
- Explain how evidence and inference are used to describe fundamental forces in nature, such as the gravitational force.
- Research the importance of gravitational forces in the space program.

What is Newton's Law of Universal Gravitation?

Long, long ago, when the universe was still young, an incredible force caused dust and gas particles to pull together to form the objects in our solar system. From the smallest moon to our enormous sun, this force created not only our solar system, but all the solar systems in all the galaxies of the universe. The force is gravity.

Defining Gravity

Gravity has traditionally been defined as a force of attraction between things that have mass. According to this conception of gravity, anything that has mass, no matter how small, exerts gravity on other matter. Gravity can act between objects that are not even touching. In fact, gravity can act over very long distances. However, the farther two

objects are from each other, the weaker is the force of gravity between them. Less massive objects also have less gravity than more massive objects.

Earth's Gravity

You are already very familiar with Earth's gravity. It constantly pulls you toward the center of the planet. It prevents you and everything else on Earth from floating away or being flung out into space as the planet spins on its axis. It also pulls objects that are above the surface—from meteors to skydivers—down to the surface. Gravity between Earth and the moon and between Earth and artificial satellites keeps all these objects circling around Earth. Gravity also keeps Earth and the other planets moving around the much more massive sun.

Q: There is a force of gravity between Earth and you and also between you and all the objects around you. When you drop a paperclip, why doesn't it fall toward you instead of toward Earth?

A: Earth is so much more massive than you that its gravitational pull on the paper clip is immensely greater.

What is the difference between mass and weight?

Mass and Weight

In everyday usage, the mass of an object is often referred to as its weight though these are in fact different concepts and quantities. In scientific contexts, mass refers loosely to the amount of "matter" in an object (though "matter" may be difficult to define), whereas weight refers to the force experienced by an object due to gravity. Mass is considered by scientists to be more fundamental that is mass does not change from place to place in the universe. One kilogram of mass is one kilogram on the surface of the Moon, Mars, or floating in space, far from other objects. Mass is immutable meaning it does not change from place to place. In other words, an object with a mass of 1.0 kilograms will weigh 9.8 Newtons (Newton is the unit of force, while kilogram is the unit of mass) on Earth (its mass multiplied by the acceleration due to gravity). Its weight will be less on Mars (where gravity is weaker), more on Saturn, and negligible in space when far from any significant source of gravity, but it will always have the same mass. In order to define weight we often overlook the fact that the definition of weight requires a support force from a solid surface. The astronauts in the International Space station are weightless because the wall, ceiling, or floor which provide support but are falling around the Earth with the astronaut. If the space station stopped moving around the Earth, it would fall like a rock toward the center of the Earth.

Weight measures the force of gravity pulling downward on an object. The SI (System International) unit for weight, like other forces, is the Newton (N). On Earth, a mass of 1 kilogram has a weight of about 9.8 Newtons, because of the pull of Earth's gravity. On the moon, which has about 1/6th the amount of gravity (due to its lower mass), the same mass would only weigh about 1.6 N. Weight is measured with a scale, like a hanging

spring scale which would measure the force with which gravity pulls an object downward.

To delve a little deeper into weight and gravity, watch this video: http://go.uen.org/b3y

Check Your Understanding

1. What is the traditional definition of gravity?

2. Define weight. What is the SI unit for weight?

3. Explain why an astronaut would weigh less on the moon than on Earth.

You may have heard a story about Isaac Newton coming up with the idea of gravity when an apple fell out of a tree and hit him in the head. The story isn't true, but seeing how things like apples fall to Earth helped Newton form his ideas about gravity, the force of attraction between things that have mass. Of course, people had known about the effects of gravity for thousands of years before Newton came along. After all, they constantly experienced gravity in their daily lives. They observed over and over again that things always fall toward the ground. However, it wasn't until Newton developed his law of gravity in the late 1600s that people knew gravity applies to everything in the universe that has mass.

What affects the gravitational pull between two objects?

Newton is widely recognized as being the first person to suggest that gravity is universal and affects all objects in the universe. That's why Newton's law of gravity is called the law of universal gravitation. Universal gravitation means that the force that causes an apple to fall from a tree to the ground is the same force that causes the moon to keep moving around Earth. Universal gravitation also means that while Earth exerts a pull on you, you exert a pull on Earth (remember Newton's 3rd Law). In fact, there is gravity

between you and every mass around you—your desk, your book, your pen. Even tiny molecules of gas are attracted to one another by the force of gravity.

Newton's law of universal gravitation had a huge impact on how people thought about the universe. A force that acts across a distance was unheard of while contact forces that push or pull on object are easy to observe. Newton's law was the first scientific law that applied to the entire universe. It explains the motion of objects not only on Earth but in outer space as well.

Key Equations

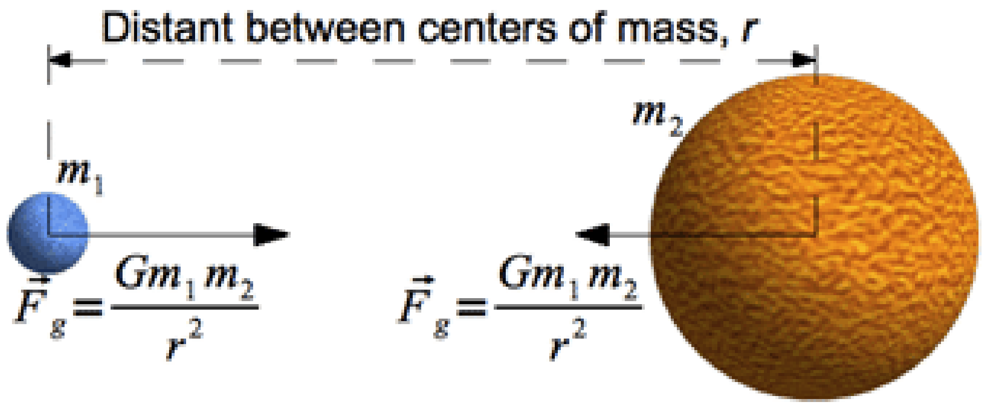
$$F_G = G\frac{m_1 m_2}{d^2}$$

F is the force of gravity between an object with mass m_1 and another object of mass m_2 that have a distance between them of d. Sometimes the symbol r is used, rather than d, to show this distance. When r is used, it represents the "orbital radius", or how far the centers of the two objects are from each other.

$$G = 6.67\text{x}10^{-11}\frac{\text{Nm}^2}{\text{kg}^2}$$

This is called the universal constant of gravitation. This was determined by measuring the force between two 1.0 kg objects whose center of masses were exactly 1.0 m apart. Look at the equation of Universal Gravitation and see what happens when you plug in masses of 1.0 kg and a distance of 1.0 m. Why would using these quantities result in a force that equals the gravitational constant?

Using astronomical data, Newton was able to formulate his ideas into an equation. This equation tells us the strength of the force of gravity between any two objects anywhere in the universe. Newton discovered that any two objects in the universe, with masses m_1 and m_2 with their centers of mass at a distance **r** apart will experience a force of mutual attraction along the line joining their centers of mass equal to: Here is an illustration of this law for two objects, for instance the earth and the sun:



Factors that Influence the Strength of Gravity

Newton's law also states that the strength of gravity between any two objects depends on two factors: the masses of the objects and the distance between them. According to this equation, the force of gravity is directly proportional to the masses of the two objects and inversely proportional to the square of the distance between them.

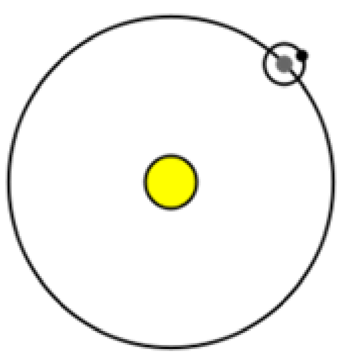
This means that objects with greater mass have a stronger force of gravity between them. For example, because Earth is so massive, it attracts you and your desk more strongly that you and your desk attract each other. That's why you and the desk remain in place on the floor rather than moving toward one another.

For example:

- If you double the mass of one of the objects, the force will also double.
- If you triple the mass of one of the objects, the force will triple.
- If you double the mass of one object and triple the mass of the other, the force will become six times (2×3=6) stronger.

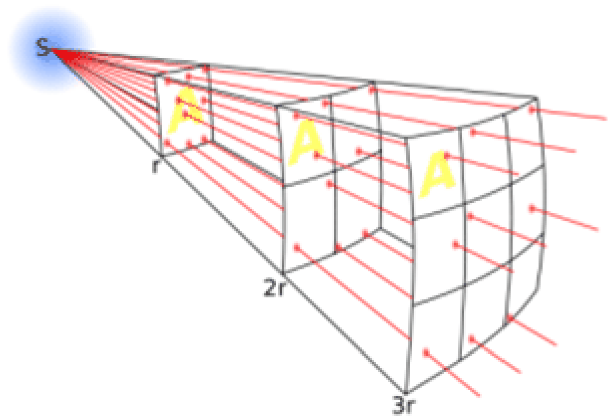
Objects that are closer together have a stronger force of gravity between them. For example, the International Space Station is closer to Earth than it is to the more massive sun, so the force of gravity is greater between the Space Station and the Earth than between the Space Station and the Sun. That's why the Space Station circles around Earth rather than the Sun. You can see this in the figure below.

Inverse Square Law



In physics, an inverse-square law is any physical law stating that a specified physical quantity or intensity is inversely proportional to the square of the distance from the source of that physical quantity. As an example, let's look at an image which shows how the intensity of light decreases according to the inverse square law.

Because the light spreads out over an area, every time we double the distance, the light intensity decreases by 1/4. If we triple the distance, the light intensity will decrease by 1/9. Both the law of Universal Gravitation and the Coulomb's Law (discussed in the next section) obey the inverse square law for distance. See if you can fill in the missing values in the next table.

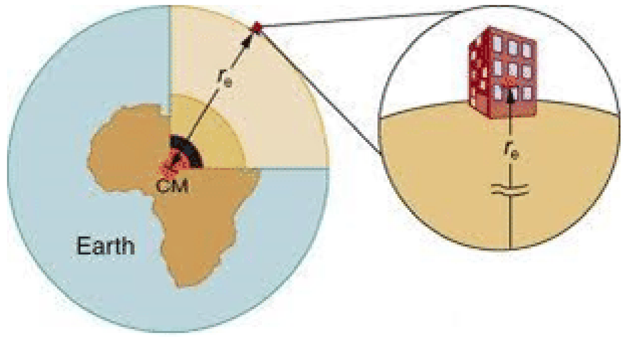


Distance	Inverse	Inverse Square
1(D)	1/1	1(F)
2(D)	½	¼(F)
½(D)	2	4(F)
3(D)		___(F)
¼(D)		____(F)
___(D)	5/6	____(F)
___(D)	8/7	____(F)
___(D)	9/10	____(F)
___(D)		4/9(F)
___(D)		49/16(F)
___(D)		0.36(F)

Gravity on the Earth's Surface

On the surface of a planet—such as Earth—the **r** in the formula is very close to the radius of the planet, since a planet's center of mass is (usually) at its center. It also does not vary by much: for instance, the Earth's radius is about 6,000,000 m. Even the height of Mt. Everest is only 8,800 m, so we can say that for objects near the surface of the Earth, the r in formula is constant and equal to the Earth's radius. This allows us to say that gravity is more or less constant on the surface of the Earth. The value on (or near) the surface of Earth for the gravitational acceleration is about 9.8 m/s^2.

Here's an illustration:



For any object near the surface of the earth, the force of gravity may be expressed as:

$$F_G = G \frac{mass_{Earth} mass_{object}}{r^2_{radius\ of\ the\ earth}}$$

In fact, an object's weight is the magnitude of the gravitational force on it. To find the weight of an object on another planet, star, or moon, use the appropriate values in the formula for the force of gravity.

Some data needed for the problems:

- The radius of the Earth is 6.4×10^6 m.
- The mass of the Earth is about 6.0×10^{24} kg.
- The mass of the Sun is about 2.0×10^{30} kg.
- The Earth-Sun distance is about 1.5×10^{11} m.
- The Earth-Moon distance is about 3.8×10^8 m.

Guidance

When using the Universal Law of Gravity formula and the constant G above, make sure to use SI units of meters and kilograms.

The direction of the force of gravity is in a straight line between two objects. It is always attractive.

Newton relied on calculus in order to prove that for a spherical object (like Earth) one can assume all of its mass is at the center of the sphere (thus in his formula, one can use the radius of Earth for the distance between a falling rock and Earth).

Newton's Laws apply to all forces; but when he developed them only one was known: gravity. Newton's major insight—and one of the greatest in the history of science—was that the same force that causes objects to fall when released is also responsible for keeping the planets in orbit.

Example 1

Determine the force of attraction between a 15.0 kg box and a 63.0 kg person if they are 3.45 m apart.

Assume that the distance given is the distance between the two centers of the objects.

$$F_g = \frac{Gm_1m_2}{d^2} = \frac{(6.67\,x\,10^{-11}\,\frac{Nm^2}{kg^2})(15.0\,kg)(63.0\,kg)}{(3.45\,m)^2} = 5.30\,x\,10^{-9}N$$

Example 2

Determine the force of attraction between the sun and the Earth.

$$F_g = \frac{Gm_1m_2}{d^2} = \frac{(6.67\,x\,10^{-11}\,\frac{Nm^2}{kg^2})(2.0x\,10^{30}\,kg)(6.0\,x\,10^{24}\,kg)}{(1.5\,x\,10^{11}\,m)^2} = 3.6\,x\,10^{22}N$$

Check Your Understanding

Identify factors that influence the strength of gravity between two objects.

Watch the short video about Newton's law of gravity at the following URL, and then answer the questions (#5-11) below.

- http://go.uen.org/b41 and http://go.uen.org/b43

5. What equation did Newton use to represent the force of gravity between two objects? What does each letter in the equation stand for? Which letter stands for a value that never changes?

6. Based on the equation, how does the force of gravity between two objects change when the mass of one of the objects doubles?

7. If the distance between the two objects doubles, how does this affect the force of gravity between them?

8. If you double one mass and quadruple the other mass, how does that affect the force of gravity between 2 objects?

9. If you double one mass, AND triple the distance between the two masses, how does that affect the force between the two objects?

10. What is Newton's law of universal gravitation?

11. Describe the relationship between the masses of two objects and the force of gravity between them.

12. Which is greater – the gravitational force that the Sun exerts on the Earth, or the force the Earth exerts on the moon?

13. Does the International Space Station orbit the Earth or the Sun? Explain.

14. Use Newton's Law of Universal Gravitation to explain why even though Jupiter has 300 times the mass of the earth, on the "surface" of Jupiter you'd weigh only 3 times what you weigh on Earth. What other factor has to be considered here?

15. How does the gravitational force change when one mass is doubled and the distance between the masses is doubled?

16. How does the gravitational force change when both masses are doubled and the distance between the masses is tripled?

Answers to Check Your Understanding

1. Gravity is the attractive force between objects with mass.
2. Weight is defined as the force of gravity
3. The moon has less gravitational acceleration on objects and, therefore, less force of gravity on objects.
4. Gravity is affected by the masses of the objects as well as the distance between the objects.
5. $F_g = \frac{Gm_1m_2}{d^2}$, m_1 and m_2 represent the masses of the two objects, measured in kg; the d (sometimes written as r) represents the distance between the centers of the two objects. G stands for the universal gravitational constant, which never changes.
6. If the mass of one object doubles, then the force of gravity doubles as well.
7. If the distance between the objects doubles, then the force of gravity reduces to ¼ as much force.
8. If you double one mass and quadruple the other mass, you will have 8 times the gravitational force.
9. If you double one mass and triple the distance between them, you will have 2/9 as much force.
10. Newton's Law of Universal Gravitation states that all objects with mass have a gravitational attraction to all other objects with mass. The force between the objects is proportional to the masses of the objects and inversely proportional to the square of the distance between the objects.
11. The relationship between the masses and force of gravity between them is proportional (or linear).
12. The Sun exerts more force on the Earth than the Earth does on the Moon.
13. The International Space Station orbits the Earth.
14. Jupiter has a lot larger mass than the Earth does, but it is also much larger. This means that the distance from the center of Jupiter to the edge of Jupiter is much larger than on Earth.
15. When one mass is doubled and the distance is also doubled, there would be ¼ of the gravitational force.
16. When both masses are doubled and the distance is tripled, the force would be 49 of the gravitational force.

3.2 Forces between Charged Particles

Objectives

- Relate the types of charge to their effect on **electric force** (i.e., like charges repel, unlike charges attract).
- Describe how the amount of **electric charge** affects the electric force.
- Investigate the relationship of distance between electrically charged objects and the strength of the electric force.
- Research and report on electric forces in everyday applications found in both nature and technology (e.g., lightning, living organisms, batteries, copy machine, electrostatic precipitators).

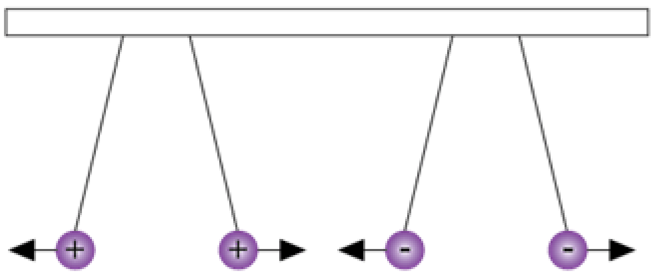
A lightning bolt is like the spark that gives you a shock when you touch a metal doorknob. Of course, the lightning bolt is on a *much* larger scale. But both the lightning bolt and spark are a sudden transfer of electric charge.

Introducing Electric Charge

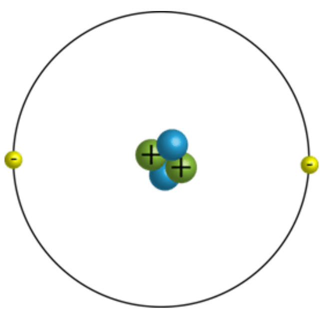
Electric charge is a physical property of particles or objects that causes them to attract or repel each other without touching. All electric charge is based on the protons and electrons in atoms. A proton has a positive electric charge, and an electron has a negative electric charge. In the figure below, you can see that positively charged protons (+) are located in the nucleus of the atom, while negatively charged electrons (-) move around the nucleus.

Electric Force

When it comes to electric charges, opposites attract, so positive and negative particles attract each other. You can see this in the diagram below. This attraction explains why negative electrons keep moving around the positive nucleus of the atom. Like charges, on the other hand, repel each other, so two positive or two negative charges push apart. This is also shown in the diagram. The attraction or repulsion between charged particles is called **electric force**. The strength of electric force depends on the amount of electric charge on the particles and the distance between them. Larger charges or shorter distances result in greater force.



Q: How do positive protons stay close together inside the nucleus of the atom if like charges repel each other?



A: There are other stronger forces in the nucleus hold the protons together.

Practice

Read the first four boxes of text at the following URL. Then write a concise paragraph explaining why direction E is the correct answer to the quick quiz.

- http://go.uen.org/b3A

Check Your Understanding

1. What is electric charge?

2. Make a simple table summarizing electric forces between charged particles.

Key Equation

$q=Ne$: Any object's charge is an integer multiple of an electron's charge.

q represents the total charge on an object, measured in units of Coulombs (which is abbreviated as C).

N represents the number of extra or missing electrons.

e represents the fundamental charge unit, 1.6×10^{-19} C.

Opposite charges attract and like charges repel.

The charge (q) of an electron (e) and proton is 1.6×10^{-19} C. An electron has a negative charge and a proton has a positive charge. This is called the fundamental charge unit. If an object has a net negative charge, it means that the object has gained electrons. If the object has a net positive charge, it means that the object has lost electrons. One can determine the number of excess electrons (or protons if positive charge) by dividing the object's charge by the fundamental charge.

Most objects are electrically neutral (equal numbers of electrons and protons). This enables gravitational force to dominate on a macro scale.

Example 1

Question:

If an object has +0.003 C of charge, how many electrons did the object lose?

Solution:

$q=Ne$

$0.003 \text{ C} = N (-1.6 \times 10^{-19} \text{ C})$

$N = -1.875 \times 10^{16}$ electrons

Answer:

1.875×10^{16} electrons fewer than protons.

Check Your Understanding

3. After sliding your feet across the rug, you touch the sink faucet and get shocked. Explain what is happening.

4. What is the net charge of the universe? Of your toaster?

5. As you slide your feet along the carpet, you end up with a net charge of +4 mC. Which of the following is true?

a) You have gained 2.5×1016 electrons.
b) You have gained 2.5×1019 electrons.
c) You have lost 2.5×1016 electrons.
d) You have lost 2.5×1019 electrons.

6. You rub a glass rod with a piece of fur. If the rod now has a charge of −0.6 μC, how many electrons have been added to the rod?

a) 3.75×10^{18} electrons
b) 3.75×10^{12} electrons
c) 6000 electrons
d) 6.00×10^{12} electrons

What is Coulomb's Law?

Electrostatics

Charles-Augustin de Coulomb (1736-1806)

All objects have positive and negative charges inside them. If the number of positive and negative charges are equal, as they most often are, then the object is neutral. Charged objects are objects with more positive charges than negative ones, or vice versa. Opposite charges attract, and similar charges repel. Electric fields are created by a net charge and point away from positive charges and towards negative charges. Many macroscopic forces can be attributed to the electrostatic forces between molecules and atoms.

Charles-Augustin de Coulomb noticed that a force existed between charged particles. He called this force **electrical force**. This force was different that the gravitational force between objects with mass. The force between charged particles varied directly with the magnitude of the charges and inversely

squared to the distance between the particles. For example, particles with a larger charge (either more negatively charged or positively charged) would have a greater force between them, He also noticed that this force between the charges could be either attractive (between opposite charges) or repulsive (between like charges). This is different that gravitational forces, because gravitational force can only be attractive. Similar to the gravitational force, the electrical force follows the inverse-square law with distance. As the distance between the objects increases, the electrical force between the objects decreases. The relationship between charge, distance, and force is called Coulomb's Law.

The Coulomb Force Law states that any two charged particles (q_1 and q_2) with charge measured in units of Coulombs at a distance r (with distance measured in units of meters) from each other will experience a force of repulsion or attraction along the line joining them equal to:

$$F_e = k\frac{q_1 q_2}{d^2}$$

This looks a lot like the Law of Universal Gravitation, which deals with attraction between objects with mass. It depends on the product of the two charges and obeys the inverse square law for distance.

For example, if you double the charge on one of the objects, the force will also double.

If you triple the charge on one of the objects, the force will triple.

If you double the charge on one object and triple the charge on the other, the force will become six times ($2 \times 3 = 6$) stronger. This is because the charge and the force are directly proportional.

If we double the distance, the force decreases by 1/4. If we triple the distance, the force will decrease by 1/9. This is because the distance and the force are inverse-squared proportional.

Coulomb's Law Summarized

There are two types of charge: positive and negative.

- Electrons have negative charge.
- Protons have positive charge.
- Magnitude of the charge is the same for electrons and protons: $e=1.6\times10^{-19}$ C. Coulomb's law is used to calculate the force between two charged particles, where k is a constant, q is the charge, and **d** (or r) is the distance between the charged particles.
- k has a value of approximately 8.99×10^9 N·m^2 / C^2

The force can be attractive or repulsive depending on the charges:

- Like charges (charges with the same sign) repel.
- Charges with opposite signs attract.

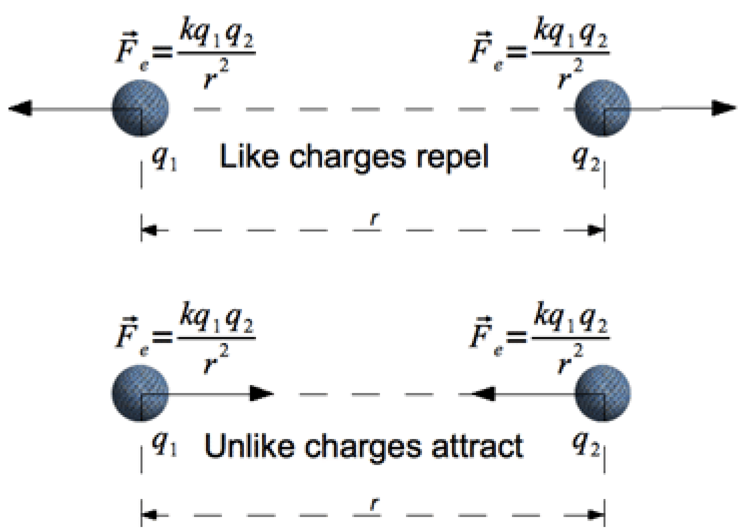
Q: What do you think would happen if the distance between the charges was cut in half?

A: The inverse of 1/2 is 2/1=2. The inverse SQUARE is $2^2 = 4$. The force would become four times stronger.

What's the difference?

The big difference is that while any two masses experience mutual attraction, two charges can either attract or repel each other, depending on whether the signs of their charges are alike:

- The sign of the force can tell you whether the two particles attract or repel.
- If the force between two charged particles is positive, then we can say the force is repulsive.
- For example, if the two charges are both positive, say +2 C and +3 C, the product of the charges will be positive.
- If the two charges are both negative, say -2 C and -3 C, the product of the charges will be also be positive.
- If the force between two charged particles is negative, then we can say the force is attractive.
- For example, if one charge is positive and the other is negative, say +2 C and -3 C, the product of the charges will be negative.



Like gravitational (and all other) forces, Coulomb forces add as vectors. Thus to find the force on a charge from an arrangement of charges, one needs to find the vector sum of the force from each charge in the arrangement.

Example 1

An electron is located 1.00×10^{-10} m to the right of another electron.

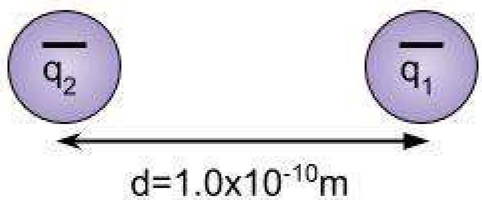
What is the force on the first electron from the second electron, F_{e1}?

What is the force on the second electron from the first electron, F_{e2}?

What if these are protons instead?

It is useful to draw a picture just to visualize the problem. The first electron is 1.00×10^{-10} m to the right of the second electron, so the appropriate drawing is:

We want to first find the force on q1 from q2.



$$F_e = k\,\frac{q_1 q_2}{d^2}$$

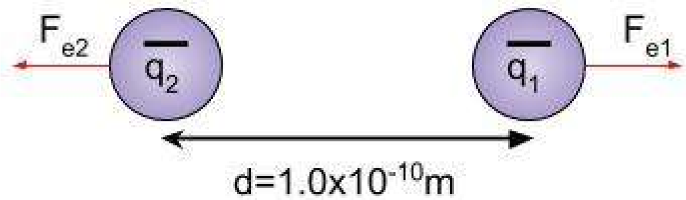
To solve this problem, we need to use Coulomb's Law and merely substitute in the appropriate values. The magnitude of Coulomb's law is:

We know that $k = 8.99\times10^{9}\,\frac{Nm^2}{C^2}$ and d (or r) is given in the problem as 1.00x10^{-10}m. The charge of an electron is e= - 1.6x10^{-19}C. So, plugging these into the equation, we get:

$$\begin{aligned} F_e &= k\,\frac{q_1 q_2}{d^2} \\ &= 8.99\times10^{9}\,\frac{Nm^2}{C^2}\;\frac{(1.6\times10^{-19}C)(1.6\times10^{-19}C)}{(1.0\times10^{-10}m)^2} \\ &= 2.31\times10^{-8}\ N \end{aligned}$$

This gives us the magnitude of the force. The sign of our answer, positive, tells us that the force is repulsive. So, the force on q_1 is directed away from q_2, or to the right. Finally, our answer is:

F_{e1}=2.31x10^{-8} N to the right

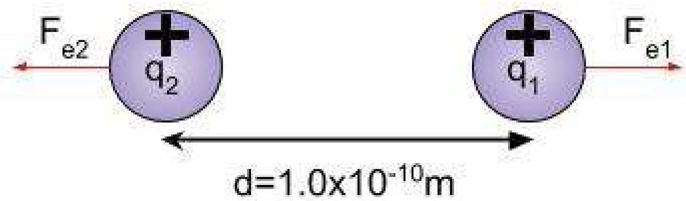


The force on q_2 is equal and opposite (remember Newton's third law?). Therefore

$F_{e2} = 2.31 \times 10^{-8}$ N to the left

Now consider the question, "What if these are protons instead?"

Most of the numbers are the same. The only difference is that the charge of a proton is $p^+ = 1.6 \times 10^{-19}$ C. So, plugging these in gives us



$$F_e = k\frac{q_1 q_2}{d^2}$$

$$= 8.99\times10^{9}\,\frac{\text{Nm}^2}{\text{C}^2}\;\frac{(1.6\times10^{-19}\text{C})(1.6\times10^{-19}\text{C})}{(1.0\times10^{-10}\text{m})^2}$$

$$= 2.31\times10^{-8}\text{ N}$$

Which is again a positive number. So the force is repulsive, and will be directed away from the other proton. Or

F_{e1}=2.31 x 10^{-8} N to the right

F_{e2}=2.31 x 10^{-8} N to the left

Notice that the answer is the same, although the charges are different.

Check Your Understanding

7. What equation did Coulomb use to represent the force of electrical attraction or repulsion between two objects? What does each letter in the equation stand for? Which letter stands for a value that never changes?

8. Based on the equation, how does the electrical force between two objects change when the mass of one of the objects doubles?

9. If the distance between the two objects is tripled, how does this affect the overall strength of the electric force between them?

10. If you triple one charge and quadruple the other charge, how does that affect the strength of the electric force between 2 objects?

11. The force between two charged particles is +50 Newtons. What could the signs of the charges be on each object? Is the electric force attractive or repulsive? How do you know?

12. List the similarities and differences between Coulomb's law and Newton's law of gravitation.

13. Use Coulomb's Law to find the force between a -0.002 C charge and a -0.006 C charge that are 10 meters apart.

What are some examples of electrostatics in real life?

The Van de Graaff Generator

What explains this shocking photo? The man in the picture is touching a device called a Van de Graaff generator. The dome on top of the device has a negative electric charge. When the man places his hand on the dome, he becomes negatively charged as well—right down to the tip of each hair!

You can see a video demonstrating a Van de Graaff generator at this URL: http://go.uen.org/b3B

Q: Why is the man's hair standing on end?

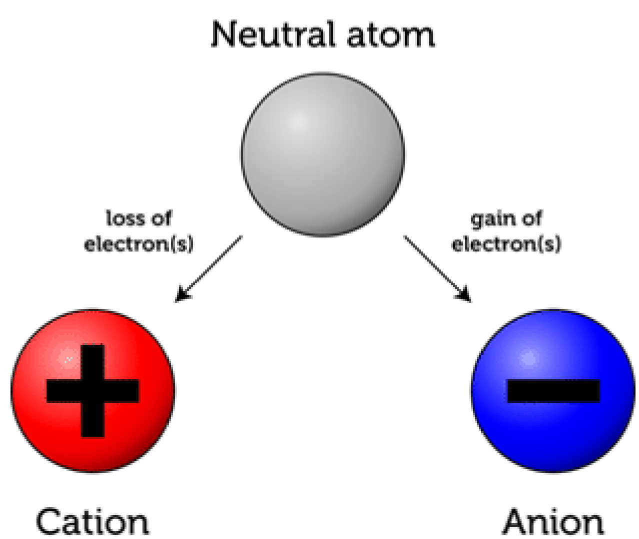
A: All of the hairs have all become negatively charged, and like charges repel each other. Therefore, the hairs are pushing away from each other, causing them to stand on end.

Transferring Electrons

The man pictured above became negatively charged because electrons flowed from the Van de Graaff generator to him. Whenever electrons are transferred between objects, neutral matter becomes charged. This occurs even with individual atoms. Atoms are neutral in electric charge because they have the same number of negative electrons as positive protons. However, if atoms lose or gain electrons, they become charged particles called ions. You can see how this happens in the figure below. When an atom loses electrons, it becomes a positively charged ion. When an atom gains electrons, it becomes a negative charged ion.

Conservation of Charge

Like the formation of ions, the formation of charged matter in general depends on the transfer of electrons, either between two materials or within a material. Three ways this can occur are referred to as conduction, polarization, and friction. All three ways are described below. However, regardless of how electrons are transferred, the total charge always remains the same. Electrons move, but they aren't destroyed. This is the law of conservation of charge.



Conduction

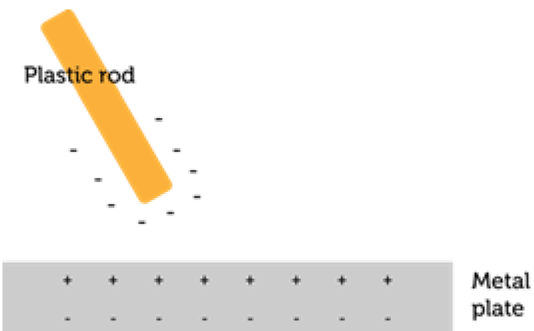
The transfer of electrons from the Van de Graaff generator to the man is an example of conduction. Conduction occurs when there is direct contact between materials that differ in their ability to give up or accept electrons. A Van de Graaff generator produces a negative charge on its dome, so it tends to give up electrons. Human hands are

positively charged, so they tend to accept electrons. Therefore, electrons flow from the dome to the man's hand when they are in contact.

You don't need a Van de Graaff generator for conduction to take place. It may occur when you walk across a wool carpet in rubber-soled shoes. Wool tends to give up electrons and rubber tends to accept them. Therefore, the carpet transfers electrons to your shoes each time you put down your foot. The transfer of electrons results in you becoming negatively charged and the carpet becoming positively charged.

Polarization

Assume that you have walked across a wool carpet in rubber-soled shoes and become negatively charged. If you then reach out to touch a metal doorknob, electrons in the neutral metal will be repelled and move away from your hand before you even touch the knob. In this way, one end of the doorknob becomes positively charged and the other end becomes negatively charged. This is called polarization. Polarization occurs whenever electrons within a neutral object move because of the electric field of a nearby charged object. It occurs without direct contact between the two objects. The figure models how polarization occurs.

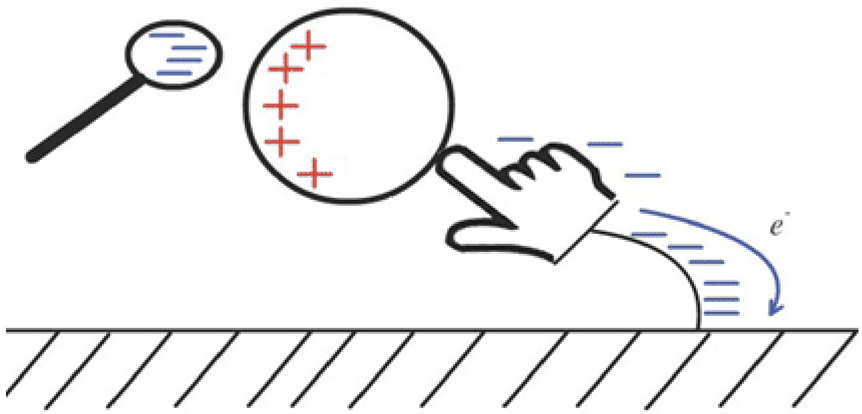


When the negatively charged plastic rod is placed close to the neutral metal plate (above), the electrons in the plate are repelled by the positive charges in the rod. The electrons move away from the rod, causing one side of the plate to become positively charged and the other side to become negatively charged.

Charging by induction is when we charge an object without touching it. There are many methods for charging objects by induction, but here is one process for charging a single object by induction.

1. First touch one finger to the neutral object to ground the object.
2. Then, bring a charged object (we'll assume it's negatively charged, but it can be either) close to the neutral object. This causes negative charges in the neutral object to be repelled through your body to the ground.
3. When the finger is removed, the neutral object will be positively charged. When charging by induction, the originally neutral object will always end up with the opposite charge.

Following is a diagram illustrating this process. When charge moves, electrons are always the ones that move. Protons cannot move between atoms.



Friction

Did you ever rub an inflated balloon against your hair? Friction between the balloon and hair cause electrons from the hair to “rub off” on the balloon. That’s because a balloon attracts electrons more strongly than hair does. After the transfer of electrons, the balloon becomes negatively charged and the hair becomes positively charged. The individual hairs push away from each other and stand on end because like charges repel each other. The balloon and the hair attract each other because opposite charges attract.

Electrons are transferred in this way whenever there is friction between materials that differ in their ability to give up or accept electrons.

Watch the animation “Balloons and Static Electricity” at the following URL to see how electrons are transferred by friction between a sweater and a balloon.

- http://go.uen.org/b3C

Q: If you rub a balloon against a wall, it may stick to the wall. Explain why.

A: Electrons are transferred from the wall to the balloon, making the balloon negatively charged and the wall positively charged. The balloon sticks to the wall because opposite charges attract.

Check Your Understanding

14. How is charge transferred by a Van de Graaff generator?

15. Compare and contrast the formation of cations and anions.

16. State the law of conservation of charge.

17. Explain how conduction and polarization occur, using the example of walking across a wool carpet in rubber-soled shoes and then reaching out to touch a metal doorknob.

18. Predict what will happen to the charges of a plastic comb and a piece of tissue paper if you rub the tissue paper on the comb. (*Hint:* Plastic tends to accept electrons and tissue paper tends to give up electrons.)

You're a thoughtful visitor, so you wipe your feet on the welcome mat before you reach out to touch the brass knocker on the door. Ouch! A spark suddenly jumps between your hand and the metal, and you feel an electric shock.

Q: Why does electric shock occurs?

A: An electric shock occurs when there is a sudden discharge of static electricity.

What Is Static Electricity?

Static electricity is a buildup of electric charges on objects. Charges build up when negative electrons are transferred from one object to another. The object that gives up electrons becomes positively charged, and the object that accepts the electrons becomes negatively charged. This can happen in several ways.

One way electric charges can build up is through friction between materials that differ in their ability to give up or accept electrons. When you wipe your rubber-soled shoes on the wool mat, for example, electrons rub off the mat onto your shoes. As a result of this transfer of electrons, positive charges build up on the mat and negative charges build up on you.

Once an object becomes electrically charged, it is likely to remain charged until it touches another object or at least comes very close to another object. That's because electric charges cannot travel easily through air, especially if the air is dry.

Q: You're more likely to get a shock in the winter when the air is very dry. Can you explain why?

A: When the air is very dry, electric charges are more likely to build up objects because they cannot travel easily through the dry air. This makes a shock more likely when you touch another object.

Static Discharge

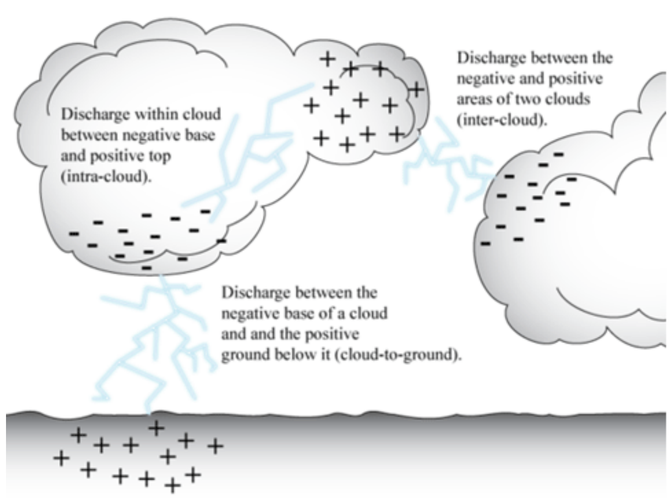
What happens when you have become negatively charged and your hand approaches the metal door-knocker? Your negatively charged hand repels electrons in the metal, so the electrons move to the other side of the knocker. This makes the side of the knocker closest to your hand positively charged. As your negatively charged hand gets very close to the positively charged side of the metal, the air between your hand and the knocker also becomes electrically charged. This allows electrons to suddenly flow from your hand to the knocker. The sudden flow of electrons is static discharge. The discharge of electrons is the spark you see and the shock you feel.

Watch the animation "John Travoltage" at the following URL to see an example of static electricity and static discharge.

- http://go.uen.org/b3D

How Lightning Occurs

Another example of static discharge, but on a much larger scale, is lightning. You can see how it occurs in the following diagram and animation as you read about it below.



- http://go.uen.org/b3E

During a rainstorm, clouds develop regions of positive and negative charge due to the movement of air molecules, water drops, and ice particles. The negative charges are

concentrated at the base of the clouds, and the positive charges are concentrated at the top. The negative charges repel electrons on the ground beneath them, so the ground below the clouds becomes positively charged. At first, the atmosphere prevents electrons from flowing away from areas of negative charge and toward areas of positive charge. As more charges build up, however, the air between the oppositely charged areas also becomes charged. When this happens, static electricity is discharged as bolts of lightning.

At the URL below, you can watch an awesome slow-motion lightning strike. Be sure to wait for the real-time lightning strike at the end of the video. You'll be amazed when you realize how much has occurred during that split-second discharge of static electricity.

- http://go.uen.org/b3F

Check Your Understanding

Watch the video at the following URL. Then answer the discussion questions. Read the background essay if you need help with any of the questions. http://go.uen.org/b3G

19. What is static electricity?

20. How does static discharge occur?

21. Explain why a bolt of lightning is like the spark you might see when you touch a metal object and get a shock.

Chapter 3 Summary

Vocabulary

- **Coulomb's Law:** Coulomb's law states that the force between two charges is proportional to the value of the two charges and inversely proportional to the square of the distance between them.
- **Electric Force:** attractive or repulsive interaction between any two charged objects.
- **Electric Charge:** the amount of excess electricity in a body (either positive or negative) depending whether there is a deficiency or excess of electrons.
- **Force:** a push or pull; an interaction between two objects.
- **Friction:** the rubbing of one body against another; while it often opposes motion that is not always the case.
- **Gravitational Force:** the attractive force between objects with mass.
- **Law of Universal Gravitation:** Law stating that gravity is a force of attraction between all objects in the universe and that the strength of gravity is greater when masses of objects are greater or distances between objects are shorter.
- **Mass:** amount of matter in an object.
- **Static Discharge:** Sudden flow of electrons from an object that has a buildup of charges.
- **Static Electricity:** Buildup of charges on an object that occurs through induction.
- **Weight:** another name for the force of gravity or the force between an object and the Earth.
- **Vector:** a quantity that has a direction and a magnitude.
- **Vector Diagram:** (also sometimes called a force diagram or free-body diagram) a sketch showing all of the forces acting on an object; used by physicists and engineers to analyze the forces acting on a body.

Summary

- Newton's law of universal gravitation states that the force of gravity affects everything with mass in the universe.
- Newton's law also states that the strength of gravity between any two objects depends on the masses of the objects and the distance between them.
- Gravity has traditionally been defined as a force of attraction between things that have mass. The strength of gravity between two objects depends on their mass and their distance apart.
- Earth's gravity constantly pulls matter toward the center of the planet. It also keeps the Moon and satellites orbiting Earth and Earth orbiting the sun.
- Weight measures the force of gravity pulling on an object. The SI unit for weight is the Newton (N).

- The mass of an object is a measurement of the amount of matter it is made of.
- Static electricity is a buildup of electric charges on objects. It occurs when electrons are transferred from one object to another.
- A sudden flow of electrons from one charged object to another is called static discharge.
- Examples of static discharge include lightning and the shock you sometimes feel when you touch another object.
- Electric charge is a physical property of particles or objects that causes them to attract or repel each other without touching.
- Particles that have opposite charges attract each other. Particles that have like charges repel each other. The force of attraction or repulsion is called electric force.
- Whenever electrons are transferred between objects, neutral matter becomes charged. For example, when atoms lose or gain electrons they become charged particles called ions.
- Three ways electrons can be transferred are conduction, friction, and polarization. In each case, the total charge remains the same. This is the law of conservation of charge.
- Conduction occurs when there is direct contact between materials that differ in their ability to give up or accept electrons.
- Polarization is the movement of electrons within a neutral object due to the electric field of a nearby charged object. It occurs without direct contact between the two objects.
- Electrons are transferred whenever there is friction between materials that differ in their ability to give up or accept electrons.

More Practice

At the following URL, read about gravity and tides. Watch the animation and look closely at the diagrams. Then answer the questions below. http://go.uen.org/b3H

1. What causes tides?
2. Which has a greater influence on tides, the moon or the sun? Why?
3. Why is there a tidal bulge of water on the opposite side of Earth from the moon?
4. When are tides highest? What causes these tides to be highest?
5. When are tides lowest? What causes these tides to be lowest?

Online Interactive Activities

Balloons (PhET Simulation): http://go.uen.org/b3I

Use this electric-hockey simulation: http://go.uen.org/b3J

Gravity and Orbits (PhET Simulation): http://go.uen.org/b3K

Answers to Check Your Understanding

1. Electric charge is related to the amount of protons and electrons in an object.
2. Student answers will vary.
3. When you rubbed your feet across the rug, you have gained a net charge by either losing or gaining electrons. When you touch the sink faucet, the faucet currently has no net charge and you have a net charge. Charge flows between you and the faucet in order to equalize the charge.
4. The net charge of the universe is zero. The net charge of your toaster is zero.
5. c. When you have a positive net charge, you have more protons than electrons. Using q=Ne, you find that N=2.5x10^{16} less electrons.
6. b. Using q=Ne, you find that N=3.75x10^{12} electrons.
7.

$$F_e = k\frac{q_1q_2}{d^2}$$

   Fe represents the electrical force between charges, q1 and q2 represent the charge of the objects and d represents the distance between the centers of the charges.
8. If the mass of one object doubles, the electrical force doesn't change at all. Coulomb's Law is based on charge, not on mass.
9. If the distance between the objects is tripled, the electric force between the objects will be 1/9th as strong as it was.
10. If you triple one charge and quadruple the other, the electrical force will increase by a factor of 12.
11. If the force is positive, the charges must have the same sign, either both positive or both negative. If the force is positive, this represents a repulsive force, since like charges repel each other.
12. Coulomb's Law and Newton's Law of Universal Gravitation are similar because they both follow the inverse-square law for distance. Coulomb's Law deals with the charge of the objects while Newton's Law deals with the mass of the objects.
13. The electrical force would be 1 x 10^3 N.
14. A Van de Graaff generator becomes negatively charged. When you touch the generator, the charge transfers to you, making you negatively charged as well.
15. Cations are formed by losing electrons, while anions are charged by gaining electrons.
16. The Law of Conservation of Charge states that the net charge of a system cannot change. So, if one object becomes more positive in charge, the other must become more negative in charge.
17. Conduction is the transfer of charge through direct conduct. When you walk across the carpet, you become negatively charged by taking electrons from the

carpet. When your hand gets near the door knob, the negative electrons in the door knob move away from your hand, leaving the door knob polarized. When you touch the door knob, charge transfers between you and the knob and you feel a shock.

18. The comb will become negatively charged and the paper will become positively charged as it loses electrons to the comb.
19. Static electricity is the buildup of electric charge on an object.
20. Static discharge happens when charge suddenly flows between objects.
21. Lightning is an example of static discharge between a cloud and another cloud or between a cloud and the Earth.

CHAPTER 4

Standard IV: Energy

Chapter Outline

Standard 4: Students will understand transfer and conservation of energy.

Objective 1: Determine kinetic and potential energy in a system.

a. Identify various types of potential energy (i.e., gravitational, elastic, chemical, electrostatic, nuclear).

b. Calculate the kinetic energy of an object given the velocity and mass of the object.

c. Describe the types of energy contributing to the total energy of a given system.

Objective 2: Describe conservation of energy in terms of systems.

a. Describe a closed system in terms of its total energy.

b. Relate the transformations between kinetic and potential energy in a system (e.g., moving magnet induces electricity in a coil of wire, roller coaster, internal combustion engine).

c. Gather data and calculate the gravitational potential energy and the kinetic energy of an object (e.g., pendulum, water flowing downhill, ball dropped from a height) and relate this to the conservation of energy of a system.

d. Evaluate social, economic, and environmental issues related to the production and transmission of electrical energy.

Objective 3: Describe common energy transformations and the effect on availability of energy.

a. Describe the loss of useful energy in energy transformations.

b. Investigate the transfer of heat energy by conduction, convection, and radiation.

c. Describe the transformation of mechanical energy into electrical energy and the transmission of electrical energy.

d. Research and report on the transformation of energy in electrical generation plants (e.g., chemical to heat to electricity, nuclear to heat to mechanical to electrical, gravitational to kinetic to mechanical to electrical), and include energy losses during each transformation.

4.1 Types of Energy

Objectives

- Identify various types of potential energy (i.e., gravitational, elastic, chemical, electrostatic, nuclear).
- Calculate the kinetic energy of an object given the velocity and mass of the object.
- Describe the types of energy contributing to the total energy of a given system.

Some chemistry reactions can be very calm and boring, while other reactions release a great deal of energy. Dynamite is a chemical that can explode violently. Here we see dynamite being used to move boulders to clear a path for a road. The chemical reactions involved here release tremendous amounts of energy very quickly.

Dynamite was invented by Alfred Nobel in 1866. Nitroglycerin, a very unstable explosive, was already known. Nobel mixed the nitroglycerin with silica to stabilize it and form a solid material. He made a fortune with this discovery and established the Nobel Foundation, which funds the Nobel Prizes every year.

What Chemical Bonds do you find in energy?

Energy in Chemical Bonds

Chemical reactions either require energy or release energy. The amount of energy needed or released depends upon the structure of the molecules that are involved in the reaction. Some reactions need to be heated for long periods in order for change to

take place. Other reactions release energy, allowing heat to be given off to the surroundings. This energy can be used in a variety of ways.

Heating

Coal, natural gas, oil—these materials can be burned to produce heat. The reaction with oxygen releases a great deal of energy that can warm homes and offices. Wood is another example of a chemical that will release energy when burned.

Transportation

A major use for petroleum products is fuel for cars, trucks, airplanes, trains, and other vehicles. The chemicals used are usually a mixture of compounds containing several carbon atoms in a chain. When the material is ignited, a massive amount of gas is created almost instantaneously. This increase in volume will move the pistons in an internal combustion engine to provide a force. A jet plane works on a similar principle. Air comes into the front of the engine and mixes with the jet fuel. This mixture is ignited and the gases formed create a lot of pressure to push the plane forward. The idea can be seen even more clearly in the case of a rocket launch. The ignition of the fuel (either solid-state or liquid) creates gases produced under great pressure that pushes the rocket up.

Batteries

A major source of energy produced by chemical reactions involves batteries. There are many types of batteries that operate using a variety of chemical reactions. The general principle behind these reactions is the release of electrons that can then flow through a circuit, producing an electrical current.

Batteries are used in a wide variety of applications, such as:

- flashlights
- watches
- computers
- cars

- hybrid vehicles – provide some power to wheels
- cell phones

Batteries in cars, computers, cell phones, and other devices are usually rechargeable. An electric current is passed through the battery to provide electrons that reverse (at least partially) the chemical reactions originally used to create the electric current. However, eventually the system can no longer be recharged and the battery has to be discarded.

Hand-Warmers

Hikers, campers, and other outdoor folks take advantage of chemical reactions to keep their hands warm. Small containers of chemicals can undergo reaction to generate heat that can be used to avoid frostbite. Some products, such as hand-warmers, contain iron filings that will react with air to release thermal energy. These types of hand-warmers cannot be reused. Other systems rely on heat being released when certain chemicals crystallize. If the warmer containing sodium acetate is placed in very hot water after use, the system can be regenerated.

Check Your Understanding

1. What kind of energy is released when we burn natural gas?

2. How does burning gasoline power a car?

3. How do batteries create energy?

What are the forms of energy?

This rock musician's electric guitar wails at a concert, as colored lights wash over the band. It's hot on stage because of the lights, but they really add to the show. The fans are thrilled and screaming with excitement. The exciting concert wouldn't be possible without several different forms of energy. Do you know what they are?

Forms of Energy

Energy or the ability to do work can exist in many different forms. The two main types of energy that we study are kinetic and potential energies. Kinetic energy is the energy of motion; any moving object possesses kinetic energy. An object at rest (relative to the observer) has no kinetic energy. Kinetic energy only deals with motion. If objects have kinetic energy that means that they are moving. The movement of charged particles produces electricity, so electricity is a type of kinetic energy. Thermal energy is also considered a type of kinetic energy, since molecules have motion. There are also many types of potential energy.

Potential energy is a little more complicated than kinetic energy. The word "potential" roughly means "ability". If you have the potential to get straight A's, you have the ability to get good grades. Whether you do or not depends on your work ethic, study habits, performance on tests and other factors, but the ability is there. In the same way, potential energy has the ability to do work on an object. Whether the work is actually done depends on the situation, but the ability is there.

Sometimes, potential energy is called "energy in storage" and that is a good way to think of it. Think of your bedroom-there are lots of places where you can store things: a closet, a dresser, under your bed, etc. Objects can store energy in different ways as well. What determines the method of storage is the force acting on the object. Potential energies include (but are not limited to):

- Gravitational Potential Energy – When you lift something up off the ground, you are giving the object gravitational potential energy. The object now has the potential to fall. The higher the object is lifted, the more gravitational potential energy it has.
- Elastic Potential Energy – When you change the shape of an object, you are giving the object elastic potential energy. A rubber band is an excellent example: as you stretch the rubber band, the elastic potential energy is waiting for you to let go so it can snap the rubber band back to its original shape. The more deformed you make an object, the more elastic potential energy it will have.
- Chemical Potential Energy – Atoms form bonds to create molecules. The bonds contain chemical potential energy. To form stronger bonds, more chemical potential energy is needed to be stored. When those bonds are broken (for example, when you eat you are breaking the bonds in your food) that chemical potential energy is released to give you energy to live.
- Electrostatic Potential Energy – Remember that charges attract or repel each other. If you bring two charges next to each other, there is a potential for these charges to attract (unlike charges) or repel (like charges). This electrostatic potential energy is what provides the energy for the charges to move closer or further away from each other.
- Nuclear Potential Energy – In the nucleus of an atom, protons are very close together. We know that two protons will repel, so in order to stop that from happening, each nucleus contains an amount of nuclear potential energy to "bind" the protons together and keep the nucleus intact. When people talk about "splitting the atom" they are referring to the nuclear potential energy that is released in the process.

Energy can also change from one form to another. The previous photo of the guitar player represents six forms of energy: mechanical, chemical, electrical, light, thermal, and kinetic energy of air molecules (sound) energy.

Q: Identify and describe six different forms of energy in the photo of the guitar player.

Check Your Understanding

4. Make a table or diagram of forms of energy. In your table or diagram, list and define five of the forms of energy described in this section. State whether the form of energy is kinetic or potential. Include an example of each form.

Answers to Check Your Understanding

1. When we burn natural gas, chemical potential energy is transferred into thermal energy (heat).

2. When gasoline in cars ignite, the reaction releases gases that expand and move pistons in the car's engine.

3. Batteries have chemicals in them that release electrons. These electrons move through wires, producing an electric current.

4. Student answers will vary.

4.2 Conservation of Energy

Objectives

- Describe a closed system in terms of its total energy.
- Relate the transformations between kinetic and potential energy in a system (e.g., moving magnet induces electricity in a coil of wire, roller coaster, internal combustion engine).
- Gather data and calculate the **gravitational potential energy** and the kinetic energy of an object (e.g., pendulum, water flowing downhill, ball dropped from a height) and relate this to the conservation of energy of a system.
- Evaluate social, economic, and environmental issues related to the production and transmission of electrical energy.

What is Potential Energy?

This diver is standing at the end of the diving board, ready to dive. After she dives and is falling toward the water, she'll have kinetic energy, or the energy of moving matter. But even as she stands motionless high above the water, she has energy. Do you know why?

Stored Energy

The diver has energy because of her position high above the pool. The type of energy she has is called potential energy. Potential energy is energy that is stored. Often, an object has potential energy because of its position or shape.

Gravitational Potential Energy

Potential energy due to the position of an object above Earth's surface is called gravitational potential energy. Like the diver on the diving board, anything that is raised up above Earth's surface has the potential to fall because of gravity. You can see an example of people with gravitational potential energy in this image.

Gravitational potential energy depends on an object's weight and its height above the ground. It can be calculated with the equation:

Gravitational Potential Energy (PE) = weight × height

Remember that weight is calculated by multiplying the mass of an object by the acceleration due to gravity, so the equation may also be written:

$$\text{Potential Energy} \begin{array}{l} = \text{weight x height} \\ = \text{mass x gravitational acceleration x height} \end{array}$$

$$PE = wh = mgh$$

Note: sometimes the letter U is used to represent gravitational potential energy, since there are so many different types of potential energy.

Consider the little girl on the sled, pictured above. She weighs 140 Newtons (remember that weight=mg), and the top of the hill is 4 meters higher than the bottom of the hill. As she sits at the top of the hill, the child's gravitational potential energy is:

PE = 140 N × 4 m = 560 Nm

Notice that the answer is given in Newton meters (Nm), which is the SI unit for energy. A Newton meter is the energy needed to move a weight of 1 Newton over a distance of 1 meter. A Newton meter is also called a Joule (J).

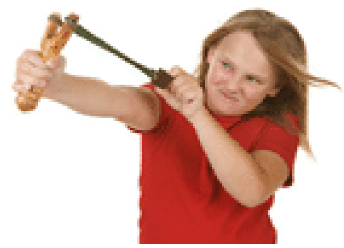
Q: The gymnast on the balance beam in the picture weighs 360 Newtons. If the balance beam is 1.2 meters above the ground, what is the gymnast's gravitational potential energy?

A: 432 N

Elastic Potential Energy

Potential energy due to an object's shape is called elastic potential energy. This energy results when an elastic object is stretched or compressed. The farther the object is stretched or compressed, the greater its potential energy is. A point will be reached when the object can't be stretched or compressed any more. Then it will forcefully return to its original shape.

Look at the pogo stick in the picture. Its spring has elastic potential energy when it is pressed down by the girl's weight. When it can't be compressed any more, it will spring back to its original shape. The energy it releases will push the pogo stick—and the girl—off the ground.



Q: This girl is giving the elastic band of her slingshot potential energy by stretching it. She's holding a small stone against the stretched band. What will happen when she releases the band?

Electrostatic Energy

Electrostatic Potential Energy is also known as electric potential energy. It results from electric charges or groups of charges that are held at a distance from each other. This results in a form of potential energy that changes with the configuration of the charges within a system. Batteries take advantage of converting chemical potential energy into electrical energy.

Other Forms of Potential Energy

All of the examples of potential energy described above involve movement or the potential to move. The form of energy that involves movement is called mechanical energy. Other forms of non-mechanical energy also involve potential energy, including chemical energy and nuclear energy. Chemical energy is stored in the bonds between the atoms of compounds. For example, food and batteries both contain chemical energy. Nuclear energy is stored in the nuclei of atoms because of the strong forces that hold the nucleus together. Nuclei of radioactive elements such as uranium are unstable, so they break apart and release the stored energy.

Check Your Understanding

1. What is gravitational potential energy?

2. Compare and contrast gravitational and elastic potential energy, and give an example of each.

3. The diver on a diving board weighs 500 Newtons. The diving board is 5 meters above the ground. What is the diver's gravitational potential energy?

4. Why does food have potential energy?

What is Kinetic Energy?

What could these four photos possibly have in common? Can you guess what it is? All of them show things that have kinetic energy.

Defining Kinetic Energy

Kinetic energy is the energy of moving matter. Anything that is moving has kinetic energy—from atoms in matter to stars in outer space. Things with kinetic energy can do work. For example, the spinning saw blade in the photo above is doing the work of cutting through a piece of metal.

Calculating Kinetic Energy

The amount of kinetic energy in a moving object depends directly on its mass and velocity. An object with greater mass or greater velocity has more kinetic energy. You can calculate the kinetic energy of a moving object with this equation:

$$\text{Kinetic Energy} = \tfrac{1}{2}\ \text{mass x velocity}^2$$

$$KE = \frac{1}{2}\ mv^2$$

This equation shows that an increase in velocity increases kinetic energy more than an increase in mass. If mass doubles, kinetic energy doubles as well, but if velocity doubles, kinetic energy increases by a factor of four. That's because velocity is squared in the equation.

Let's consider an example. The figure below shows Juan running on the beach with his dad. Juan has a mass of 40 kg and is running at a velocity of 1 m/s. How much kinetic energy does he have?

Substitute these values for mass and velocity into the equation for kinetic energy:

$$KE = \frac{1}{2} mv^2 = \frac{1}{2}\ 40\ kg \times (1\ m/s)^2$$
$$= 20\ kg\ m^2/s^2$$
$$= 20\ J$$

Notice that the answer is given in joules (J), or Nm, which is the SI unit for energy. One joule is the amount of energy needed to apply a force of 1 Newton over a distance of 1 meter.

What about Juan's dad? His mass 80 kg, and he's running at the same velocity as Juan (1 m/s). Because his mass is twice as great as Juan's, his kinetic energy is twice as great, so 40 J.

Q: What is Juan's kinetic energy if he is now traveling 2 m/s?

A: 80 J

Supplemental Links

This is a video introduction to kinetic energy and how it is related to work from Flipping Physics:

- http://go.uen.org/b3L

You can review kinetic energy at this link:

- http://go.uen.org/b3M

Check Your Understanding

5. What is kinetic energy?

6. The kinetic energy of a moving object depends on its mass and its

- volume
- speed
- distance
- Acceleration

7. The bowling ball is whizzing down the bowling lane at 4 m/s. If the mass of the bowling ball is 7 kg, what is its kinetic energy?

8. A 10 kg box is 2 m above the surface of Earth. What is the gravitational potential energy of the box at this height (in reference to the ground)?

Is Energy always conserved?

Key Equations: Conservation of Energy

$\Sigma E_{intitial} = \Sigma E_{final}$

The total energy does not change in closed systems

∑ is the Greek letter "Sigma". It is sometimes referred to as "summation" and means the total amount or the net amount.

Energy is conserved in a closed system. That is, if you add up all the energy of an object(s) at one time it will equal all the energy of the same object(s) at a later time. A closed system is a system where no energy is transferred in or out. The total energy of the universe is a constant (i.e. it does not change). The problems below do not consider the situation of energy transfer (called work). So friction and other sources where energy leaves the system are not present. Thus, one simply adds up all the potential energy and kinetic energy before and sets it equal to the sum of the potential and kinetic energy after.

$$K_{initial} + U_{initial} = K_{final} + U_{final}$$

Suppose a 10 kg box is sitting on a shelf that is 5 m above the ground. While it is on the top of the shelf, the box has a gravitational potential energy of 490 J and 0 J of kinetic energy (because it is not moving). The total **mechanical energy** of the box is 490 J. Mechanical energy is the sum of potential and kinetic energies that an object has.

If the box falls, the potential energy that the box had while it was on the shelf will be transferred into kinetic energy. When the box is halfway between the floor and the shelf (at a height of 2.5 m), it will have only 245 J of potential energy. Where did the rest of the energy go? Since energy cannot be created or destroyed, it didn't just disappear. The remaining potential energy is now kinetic energy. When the box is half way down to the floor, it has 245 J of potential energy and 245 J of kinetic energy. It still has a total energy of 490 J.

When the box has fallen 4 meters (so it is only 1 meter above the ground), the potential energy is only 50 J. How much kinetic energy does it have? It now has 440 J of kinetic energy and is moving with a speed of about 9.4 m/s. When it hits the ground, it will have no more potential energy and 490 J of kinetic energy.

At any given point, the total energy must be the same. The energy can change form or type, but all energy must be accounted for. Sometimes the energy changes into thermal energy (heat), sound, electrical energy, light, or other types of energy.

Check Your Understanding

9. Describe how a simple roller coaster works, in terms of energy conservation?

10. How does the height of the first hill affect the maximum speed of the roller coaster?

11. Suppose an object was lifted to a height that was twice its original height. How would the gravitational potential energy of the object change?

12. If a box has a potential energy of 350 J while it is up on a shelf and it falls, what will be the kinetic energy of the box as it reaches the ground?

13. Suppose you are remodeling a roller coaster. You want the speed at the bottom of the first hill to be double what it currently is. By what factor should the height of the first hill be increased?

Answers to Check Your Understanding

1. Gravitational potential energy is the stored up energy in an object and is proportional to its mass and height above the surface of the Earth.

2. Gravitational potential energy and elastic potential energy are both related to the position of an object and the ability to do work on the object. Gravitational potential energy exists in objects that are above the Earth's surface (or a different frame of reference), while elastic potential energy is stored from the change in shape of an object being stretched or compressed. An example of an object with gravitational potential energy would be a book sitting on a shelf. An example of an object with elastic potential energy would be a stretched-out rubber band.

3. The gravitational potential energy of the diver can be found using

Potential Energy = weight x height

PE = 500 N x 5 m = 2500 J

4. Food has a chemical potential energy. As the food is processed in our bodies, that energy is released and can be transferred into other types of energy, like kinetic energy or thermal energy.

5. Kinetic energy is the energy that an object has while it is moving.

6. b. The kinetic energy of an object depends on its mass and speed (or velocity).

7. The kinetic energy of the bowling ball is 56 Joules.

8. 220 N

9. Roller coaster does work on the roller coaster car by pulling it up a hill with a chain. Now, the roller coaster has gravitational potential energy. As the roller coaster travels down the first hill, the gravitational potential energy is transferred to kinetic energy and the car picks up speed. Throughout the ride, the energy is transferred between gravitational potential energy and kinetic energy.

10. If the height of the first hill was greater, the system would have more total mechanical energy in. That means that the higher the first hill is, the faster the car will go when it reaches the bottom of the first hill.

11. If the height of the roller coaster was doubled, the gravitational potential energy would be doubled as well.

12. If the box started at rest on the shelf, then the total mechanical energy of the box is 350 Joules. This energy will stay conserved. As it reaches the ground, its potential energy is 0 Joules, so the kinetic energy is now 350 Joules.

13. If you want to double the speed, you will need to increase the kinetic energy by a factor of 4 (quadruple), since KE = ½ mass x velocity^2 . In order to increase the kinetic energy at the bottom of the first hill by a factor of 4, you must also increase the potential energy at the top of the hill by a factor of 4. This will happen if you quadruple the height of the first hill.

4.3 Energy Transfer

Objectives

- Describe the loss of useful energy in energy transformations.
- Investigate the transfer of heat energy by conduction, convection, and radiation.
- Describe the transformation of mechanical energy into electrical energy and the transmission of electrical energy.
- Research and report on the transformation of energy in electrical generation plants (e.g., chemical to heat to electricity, nuclear to heat to mechanical to electrical, gravitational to kinetic to mechanical to electrical), and include energy losses during each transformation.

How does energy change form?

Changing Energy

Watching movies, eating hot popcorn, and many other activities depend on electrical energy. Most electrical energy comes from the burning of fossil fuels, which contain stored chemical energy. When fossil fuels are burned, the chemical energy changes to thermal energy and the thermal energy is then used to generate electrical energy. These are all examples of energy conversion. Energy conversion is the process in which one kind of energy changes into another kind. When energy changes in this way, the energy isn't used up or lost. The same amount of energy exists after the conversion as before. Energy conversion obeys the law of conservation of energy, which states that energy cannot be created or destroyed.

How Energy Changes Form

Energy, whether classified as kinetic or potential, can change into any other form of either type. Frequently the energy changes into two or more different forms. For example, the popcorn machine changes electrical energy into thermal energy. The thermal energy in turn changes to both mechanical energy (the corn popping) and into mechanical energy of air molecules moving (sound).

Kinetic-Potential Energy Changes

Mechanical energy commonly changes between kinetic and potential energy. Kinetic energy is the energy of moving objects. Potential energy is energy that is stored in objects, typically because of their position or shape. Kinetic energy can be

used to change the position or shape of an object, giving it potential energy. Potential energy gives the object the potential to move. If it does, the potential energy changes back to kinetic energy.

That's what happened to Sari. After she and Daniel left the theater, the storm cleared and they went to the pool. When she was at the top of the slide, she had potential energy. Why? She had the potential to slide into the pool because of the pull of gravity. As she moved down the slide, her potential energy changed to kinetic energy. By the time she reached the pool, all the potential energy had changed to kinetic energy.

Q: How could Sari regain her potential energy?

Q: A roller coaster is another fun example of changes between kinetic and potential energy. Can you think of other examples of energy changing between kinetic and potential energy?

In a frictionless world, the changes between kinetic and potential energy would have no other types of energy to account for. Sari's kinetic energy at the bottom of the water slide would be exactly the same amount as the potential energy that she had at the top of the slide. Since the slide has some friction, some of her energy was transferred into heat or sound. When all energy is accounted for, the total amount of energy at any given point is the same.

Heat loss

Suppose Sari now went for a jog around the park. She has chemical potential energy supplied to her by the food that she has consumed. This chemical potential energy will change to kinetic energy as she runs. Some of that energy will also be transferred into thermal energy. She will get hot from running. Her running shoes will make a sound on the pavement. Whenever energy is transformed between types, some useful energy will be lost to the environment. This doesn't mean that energy is destroyed. All energy is still accounted for – it just isn't necessarily kinetic or potential energy.

Most of the time, energy that has been transferred to heat is considered to be "lost" because it is really hard to turn that thermal energy back into any other form of energy. The amount of energy not "lost" to heat, compared with the original amount of energy, is how efficient the transfer of energy was.

Power plants

Sometimes heat being lost during an energy transformation is desirable. Consider a power plant. A nuclear power plant works by changing nuclear energy into heat, then changing that heat into mechanical energy, and then changing that mechanical energy into electrical energy. A coal power plant works by burning coal, which has chemical potential energy. This chemical energy will transfer into heat to turn water into steam. This steam turns a turbine. The turbine has kinetic energy, since it is moving. The energy is the transferred into electrical energy. This electrical energy is transported to homes and businesses through electrical wires and then converted into a variety of other types of energy.

Check Your Understanding

1. Research and report on the energy transformations that describe how an electrical generation plant works.

2. Name and describe at least three different energy transformations that happened in your life today.

How is heat transferred?

Heat is transferred from one object to another in one of three forms:

- **Conduction:** when heat transfers between objects that are in direct contact (touching).
- **Convection:** when heat transfers through moving currents in fluids (liquids or gases).
- **Radiation:** when heat transfers through electromagnetic waves.

Conduction

Suppose you are boiling water on the stove top so that you can make some pasta. The pot and the burner of the stove are touching, so the heat energy is transferred by conduction. Also imagine that you are holding an ice cube in your hand. The ice cube will melt because heat from your body is being transferred into the ice cube by conduction. Using a curling iron to style hair is also an example of conduction.

Hands feel cold when they're holding ice because they lose thermal energy to the ice.

Hair feels warm after a hot curling iron passes over it because it gains thermal energy from the curling iron.

Convection

Have you ever melted chocolate in a double-boiler? When the water in the pot boils, the water moves in currents. These currents heat up the sides of the second pot full of chocolate, causing the chocolate to melt. Also, using a clothes dryer works to dry your clothes by circulating warm air around clothing as it moves in the dryer. A fireplace that has a fan to circulate warm air into the room is another example of convection. The mantle of the earth also moves in currents. The hot rock is less dense, so it moves near the top of the mantle and then cools. The cooler rocks are denser and move down toward the bottom of the mantle. The cycle continues and a current is formed. Heat is being transferred through these currents and this is called convection.

Radiation

The transfer of heat through electromagnetic waves is called radiation. Electromagnetic waves are waves that can travel through empty space. The energy from the Sun travels through the vacuum of space to our Earth. The Earth is definitely not in direct contact with the Sun (thank goodness!). There are no fluids in space, so the energy can't travel by convection. This energy gets to Earth through radiation. The Earth and its inhabitants are dependent of the energy from the Sun for heat and light.

When heat from a fireplace travels through the air to warm a room, it uses both convection and radiation to heat the room. As the warm air circulates to the room by currents, it is called convection, but the heat energy from the fireplace also uses radiation to heat the room as the heat travels through infrared rays.

Check Your Understanding

3. Give three examples of heat being transferred by conduction.

4. Give three examples of heat being transferred by convection.

5. Give three examples of heat being transferred by radiation.

Answers to Check Your Understanding

1. Student answers will vary.

2. Student answers will vary, but may include such things like walking to school changes chemical potential energy into kinetic energy, or using a calculator transfers electrical energy into light energy.

3. Answers may include touching an ice cube to melt it, heating food on a stove top, or rubbing your hands together to warm them.

4. Answers may include cooking food in a convection oven, drying clothes in a dryer, or using a hair drying to blow dry your hair.

5. Answers may include heating food in a microwave, being warmed by standing near a fire, or the Earth being warmed by the Sun.

Chapter 4 Summary

Vocabulary

- **Conduction:** the transfer of heat through direct contact.
- **Convection:** the transfer of heat through currents in a fluid.
- **Elastic Potential Energy:** is the potential energy of an object due to its shape. It results when an object is either stretched or compressed, depends upon spring constant (k).
- **Energy:** the capacity for doing work; may exist as potential, kinetic, thermal, chemical, electrical, nuclear, and other various forms.
- **Gravitational Potential Energy:** depends on an object's weight and its height above the ground. (PE = mgh= mass x gravitational acceleration x height).
- **Kinetic Energy:** Energy of moving matter.
- **Law of Conservation of Energy:** states that the total energy of an isolated system remains constant—it is said to be conserved over time. Energy can neither be created nor destroyed; rather, it transforms from one form to another.
- **Potential Energy:** Stored energy an object has because of its position or shape.
- **Radiation:** the transfer of energy through electromagnetic waves.

Summary

- Some chemical reactions release energy.
- This energy can be used in a variety of ways.
- Potential energy is energy that is stored.
- Gravitational potential energy is due to the position of an object above Earth's surface. The object has the potential to fall due to gravity. Gravitational potential energy depends on an object's weight and its height above the ground

$$\text{Potential Energy} \begin{array}{l} = \text{weight x height} \\ = \text{mass x gravitational acceleration x height} \end{array}$$

$$PE = wh = mgh$$

- Elastic potential energy is due to an object's shape. It results when an elastic object is stretched or compressed. The more it is stretched or compressed, the greater its elastic potential energy is.
- Chemical energy and nuclear energy are other forms of potential energy.
- Kinetic energy (KE) is the energy of moving matter. Anything that is moving has kinetic energy.
- The amount of kinetic energy in a moving object depends directly on its mass and velocity. It can be calculated with the equation:

Kinetic Energy = ½ mass x velocity^2

$$KE = \frac{1}{2} mv^2$$

NOTE: Squaring any number, whether positive or negative, results in a positive number. Velocity can be positive or negative, depending on the direction of travel, but kinetic energy can never be negative. The kinetic energy of an object is dependent on speed and mass.

- Energy conversion is the process in which energy changes from one form or type to another. Energy is always conserved in energy conversions.
- Different forms of energy—such as electrical, chemical, and thermal energy—often change to other forms of energy.
- Mechanical energy commonly changes back and forth between kinetic and potential energy.
- Conduction is the transfer of heat through direct contact.
- Convection is the transfer of heat through currents.
- Radiation is the transfer of heat through empty space.

More Review Questions

- Define energy conversion.
- Relate energy conversion (from one form of energy to another) to the law of conservation of energy.
- Describe an original example of energy changing from one form to two other forms.
- Explain how energy changes back and forth between kinetic and potential energy when you jump on a trampoline. Include a sketch to help explain the energy conversions taking place while you jump.
- Research and report on the transformation of energy. Describe how your cell phone receives a charge and include how the electricity is formed. Also describe the process of the battery storing energy and then using it when you make a call.

Online Interactive Activities

Watch this explanation about roller coasters: http://go.uen.org/b3N

Check out this interactive activity about the energy transformations at a skate park. http://go.uen.org/b3O

A pogo stick spring compresses and then returns to its original shape in this animation. http://go.uen.org/b3P http://go.uen.org/b3Q

CHAPTER 5

Standard V: Waves

Chapter Outline

Standard 5: Students will understand the properties and applications of waves.

Objective 1: Demonstrate an understanding of mechanical waves in terms of general wave properties.

a. Differentiate between period, frequency, wavelength, and amplitude of waves.

b. Investigate and compare reflection, refraction, and diffraction of waves.

c. Provide examples of waves commonly observed in nature and/or used in technological applications.

d. Identify the relationship between the speed, wavelength, and frequency of a wave.

e. Explain the observed change in frequency of a mechanical wave coming from a moving object as it approaches and moves away (i.e., Doppler effect).

f. Explain the transfer of energy through a medium by mechanical waves.

Objective 2: Describe the nature of electromagnetic radiation and visible light.

a. Describe the relationship of energy to wavelength or frequency for electromagnetic radiation.

b. Distinguish between the different parts of the electromagnetic spectrum (e.g., radio waves and x-rays or visible light and microwaves).

c. Explain that the different parts of the electromagnetic spectrum all travel through empty space and at the same speed.

d. Explain the observed change in frequency of an electromagnetic wave coming from a moving object as it approaches and moves away (i.e., Doppler effect, red/blue shift).

e. Provide examples of the use of electromagnetic radiation in everyday life (e.g., communications, lasers, microwaves, cellular phones, satellite dishes, visible light).

5.1 Energy Transfer in Waves

Objectives

- Differentiate between **period**, **frequency**, wavelength, and **amplitude** of waves.
- Investigate and compare **reflection**, **refraction**, and **diffraction** of waves.
- Provide examples of waves commonly observed in nature and/or used in technological applications.
- Identify the relationship between the speed, **wavelength**, and **frequency** of a **wave**.
- Explain the observed change in frequency of a **mechanical wave** coming from a moving object as it approaches and moves away (i.e., **Doppler effect**).
- Explain the transfer of energy through a medium by mechanical waves.

No doubt you've seen this happen. Droplets of water fall into a body of water, and concentric circles spread out through the water around the droplets. The concentric circles are waves moving through the water.

What is a Mechanical Wave?

Waves in Matter

The waves in the picture above are examples of mechanical waves. A mechanical wave is a disturbance in matter that transfers energy through the matter. A mechanical

wave starts when matter is disturbed. A source of energy is needed to disturb matter and start a mechanical wave.

Q: Where does the energy come from in the water wave pictured above?

A: The energy comes from the falling droplets of water, which have kinetic energy because of their motion.

The Medium

The energy of a mechanical wave can travel only through matter. The matter through which the wave travels is called the **medium** (plural, media). The medium in the water wave pictured above is water, a liquid. But the medium of a mechanical wave can be any state of matter, even a solid.

Q: How do the particles of the medium move when a wave passes through them?

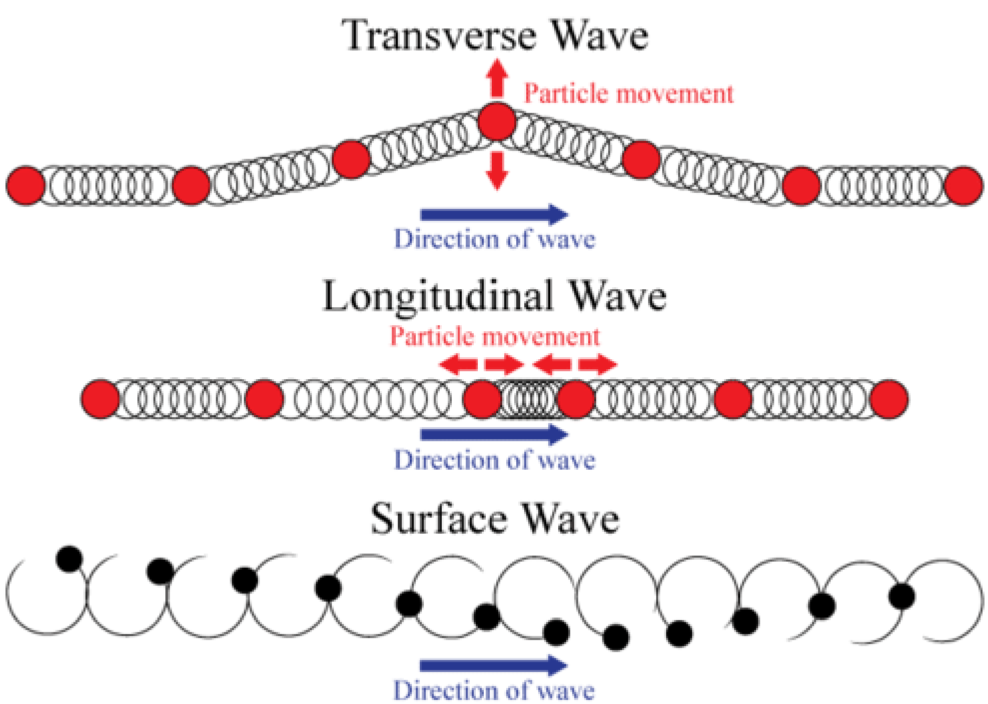
A: The particles of the medium just vibrate in place. As they collide, they pass the energy of the disturbance to the particles next to them, which pass the energy to the particles next to them, and so on. The individual particles of the medium don't actually travel along with the wave. Only the energy of the wave travels through the medium.

Types of Mechanical Waves

There are three types of **mechanical waves**: transverse, longitudinal, and surface waves. They differ in how particles of the medium move.

You can see this in the figure and in the animation at the following URL.

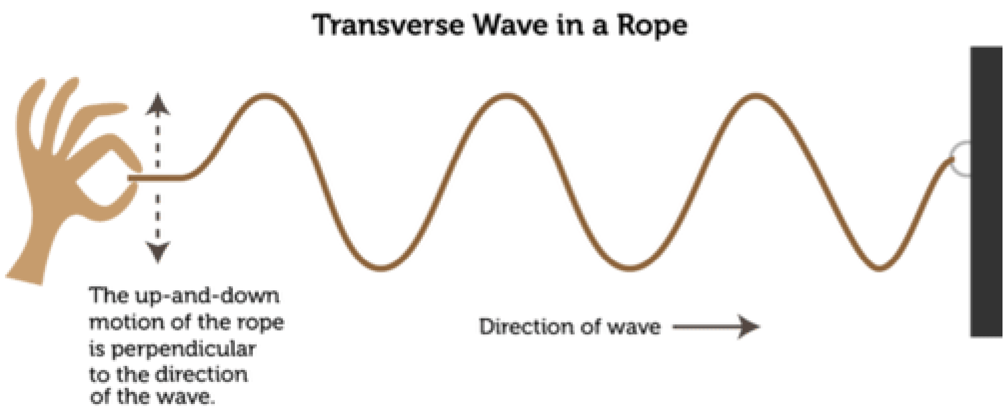
- http://go.uen.org/b4o



- In a transverse wave, particles of the medium vibrate up and down perpendicular to the direction of the wave.
- In a longitudinal wave, particles of the medium vibrate back and forth parallel to the direction of the wave.
- In a surface wave, particles of the medium vibrate both up and down and back and forth, so they end up moving in a circle.

What Is a Transverse Wave?

A transverse wave is a wave in which particles of the medium move at right angles, or perpendicular, to the direction that the wave travels. Another example of a transverse wave is the wave that passes through a rope with you shake one end of the rope up and down, as in the figure. The direction of the wave is down the length of the rope away from the hand. The rope itself moves up and down as the wave passes through it.



You can watch a video of a transverse wave in a rope at this URL:http://go.uen.org/b3T

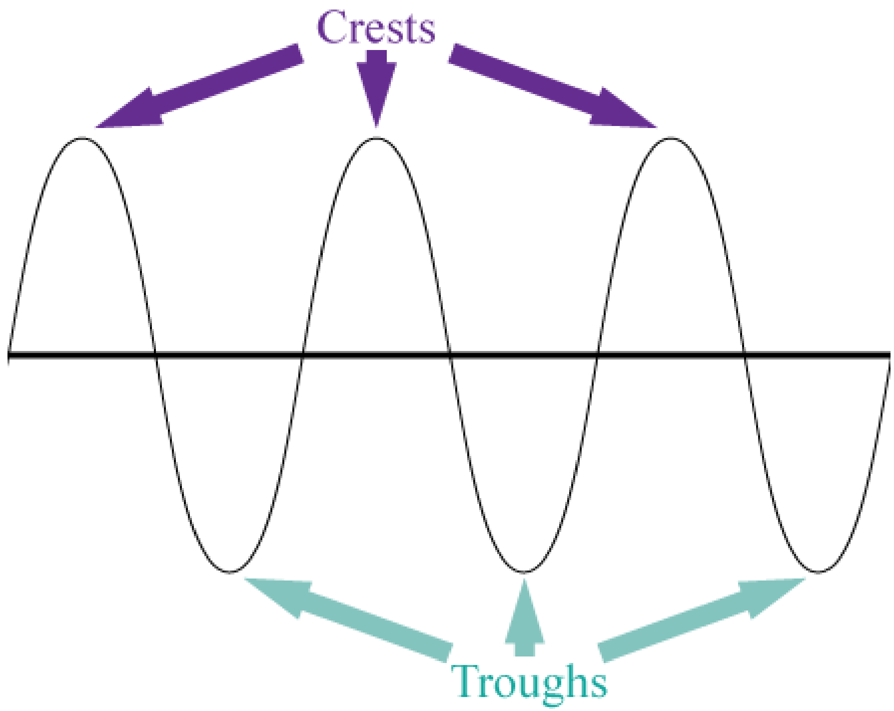
To see a transverse wave in slow motion, go to this URL:http://go.uen.org/b3U

Q: When a guitar string is plucked, in what direction does the wave travel? In what directions does the string vibrate?

A: The wave travels down the string to the end. The string vibrates up and down at right angles to the direction of the wave.

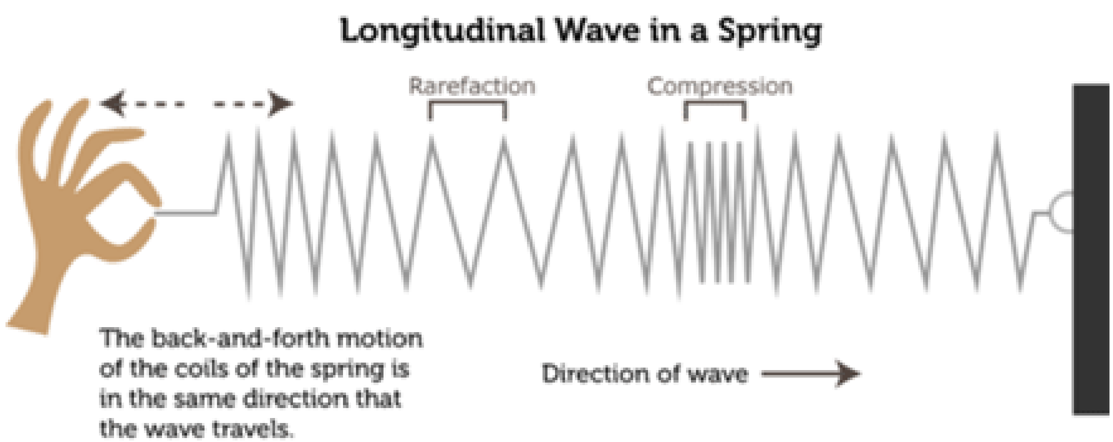
Crests and Troughs

A transverse wave is characterized by the high and low points reached by particles of the medium as the wave passes through. The high points are called crests, and the low points are called troughs. You can see both in the figure.



What Is a Longitudinal Wave?

A longitudinal wave is a type of mechanical wave. A mechanical wave is a wave that travels through matter, (referred to as a medium, such as air or water). In a longitudinal wave, particles of the medium transfer kinetic energy through collisions in a direction that is parallel to the direction that the wave travels. You can see this in the figure. The person's hand pushes and pulls on one end of the spring. The energy of this disturbance passes through the coils of the spring to the other end.



You can see a video of a longitudinal wave in a spring at this URL: https://youtu.be/ubRlaCCQfDk

Check Your Understanding

1. Explain the difference between a transverse wave and a longitudinal wave.

2. List at least 2 real-world examples of

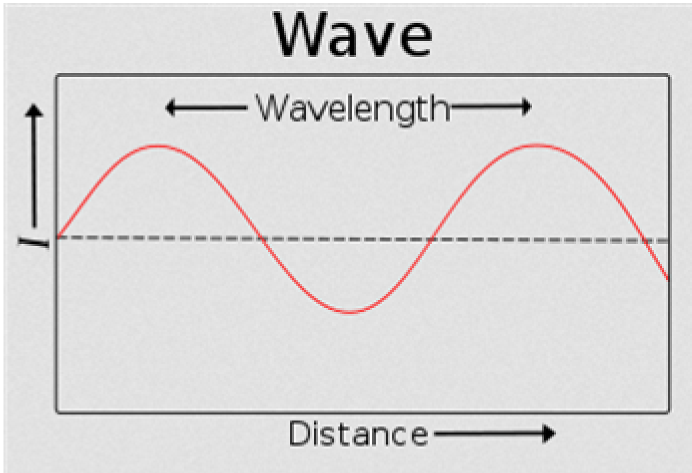
- Transverse waves.
- Longitudinal waves.

3. The highest point on a transverse wave is the (a)_______ while the lowest part is the (b)_______.

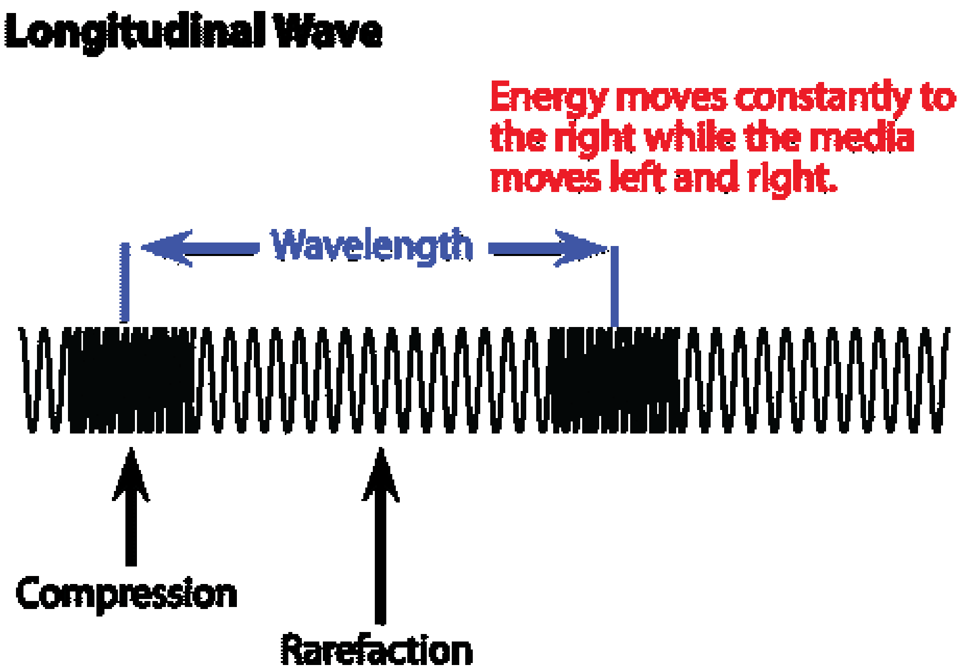
Wavelength

Wavelength is one way of measuring the size of waves. It is the distance between two corresponding points on adjacent waves, and it is usually measured in meters. How it is measured is a little different for transverse and longitudinal waves.

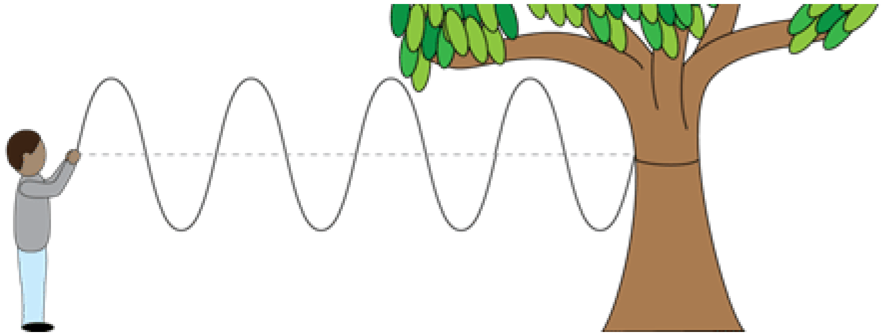
In a transverse wave, particles of the medium move up and down at right angles to the direction that the wave travels. The wavelength of a transverse wave can be measured as the distance between two adjacent crests, or high points, as shown in the diagram.



In a longitudinal wave, particles of matter move back and forth in the same direction that the wave travels. The wavelength of a longitudinal wave can be measured as the distance between two adjacent compressions, as shown in the diagram. Compressions are the places where particles of the medium crowd close together as the energy of the wave passes through.



At the following URL, watch the animation to see examples of wavelength. Also, get a feel for wavelength by playing with the wave generator. http://go.uen.org/b4p



Imagine making transverse waves in a rope, like the person in the sketch above. You tie one end of the rope to a tree or other fixed point, and then you shake the other end of the rope up and down with your hand. You can move the rope up and down slowly or quickly. How quickly you move the rope determines the frequency of the waves.

You can make a longitudinal wave by moving a slinky back and forth in the same direction as illustrated in a previous diagram.

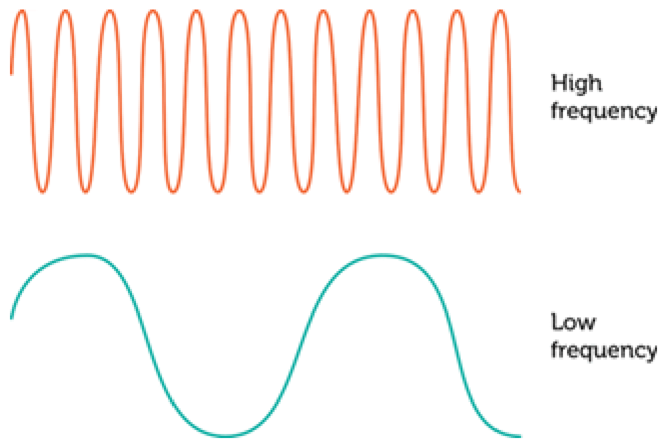
What is the difference between the period and frequency of a wave?

Period

The period, commonly represented by the symbol T, is the amount of time for the harmonic motion to repeat itself, or for the object to go one full cycle. The period of a wave is the time it takes the object to return to its exact starting point and starting direction. The period of a wave depends on the period of oscillation of the object creating the wave.

Frequency

The number of waves that pass a fixed point in a given amount of time is wave frequency. Wave frequency can be measured by counting the number of wavelengths of waves that pass the fixed point in 1 second or some other time period. The higher the number is, the greater the frequency of the waves. The SI unit for wave frequency is the hertz (Hz), where 1 hertz equals 1 wave cycle passing a fixed point in 1 second. The figure below shows high-frequency and low-frequency transverse waves.



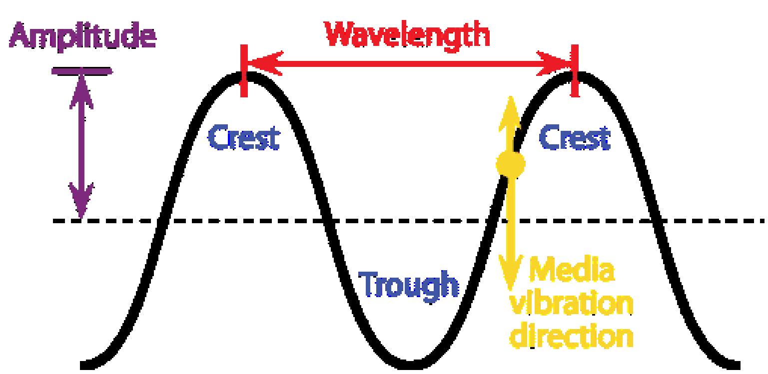
If these waves were traveling at the same speed, you can easily see that the wave with the higher frequency also has the shortest wavelength.

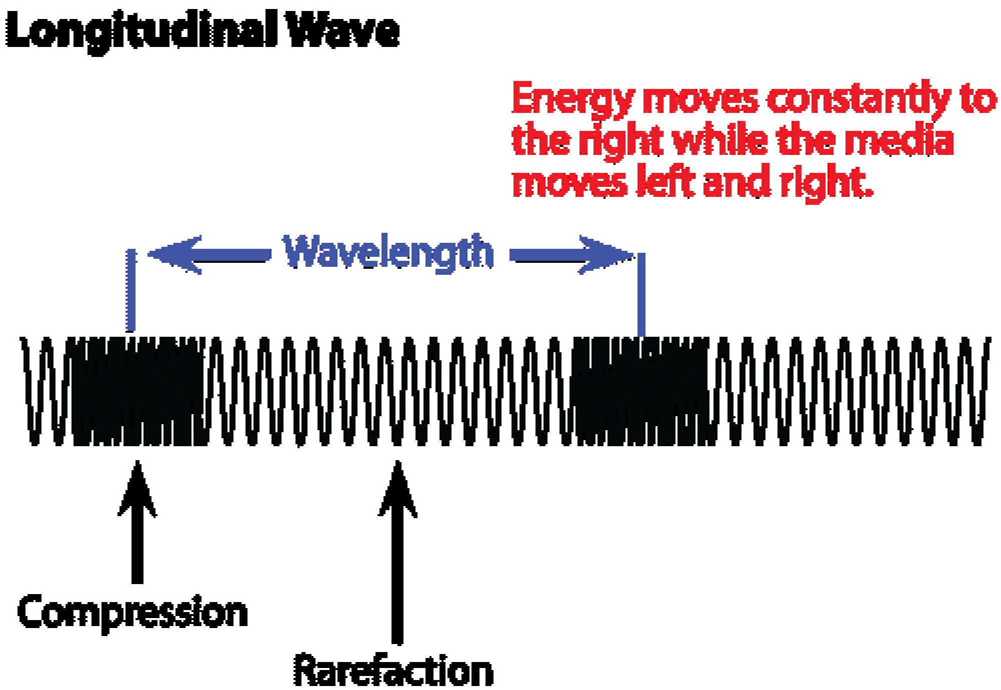
You can simulate transverse waves with different frequencies at this URL:

- http://go.uen.org/b3V

Amplitude

Wave amplitude is the maximum distance the particles of the medium move from their equilibrium (or resting) position when a wave passes through. The resting position of a particle of the medium is where the particle would be in the absence of a wave. The figures show the amplitudes of two different types of waves: transverse and longitudinal waves.





Remember that in a transverse wave, particles of the medium move at right angles to the direction of the wave. Wave amplitude of a transverse wave is the difference in height between the crest and the resting position or the difference in height between the resting position and the trough. Wave amplitude is not the difference in height between the crest and the trough. The higher the crests are, the greater the amplitude of the wave. The amplitude of a wave is related to the amount of energy traveling through the medium. So, the greater the amplitude, the greater the amount of energy traveling through the medium.

In a longitudinal wave, particles of the medium move back and forth in the same direction as the wave. Wave amplitude of a longitudinal wave is related to the distance between particles of the medium.

Q: What determines a wave's amplitude?

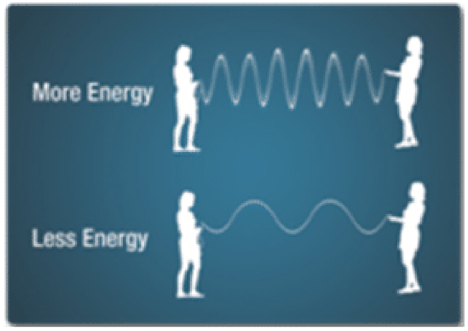
A: Wave amplitude is determined by the energy of the disturbance that causes the wave.

You can simulate waves with different amplitudes in the animation at this URL:

- http://go.uen.org/b3W

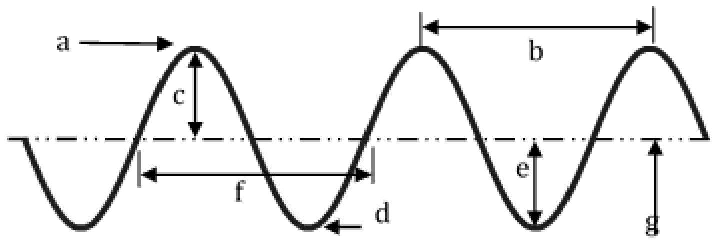
Wave Frequency and Energy

The **frequency** of a wave is the same as the frequency of the vibrations that caused the wave. For example, to generate a higher-frequency wave in a rope, you must move the rope up and down more quickly. This takes more **energy**, so a higher-frequency wave has more energy than a lower-frequency wave with the same amplitude. You can see examples of different frequencies in the figure. (Amplitude is the distance that particles of the medium move when the energy of a wave passes through them.)



Check Your Understanding

4. The illustration below shows a series of transverse waves. Label each part in the space provided. (You may use an answer more than once.)



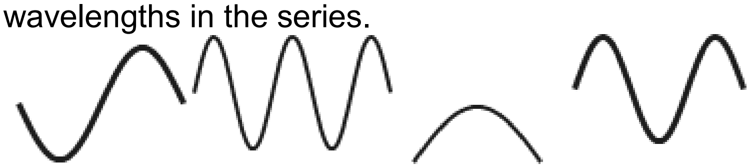
Fill in the blanks:

5. Waves transfer _____________ from one place to another.

6. The _______ is the height of the wave.

7. The distance from one crest to the next is the _______.

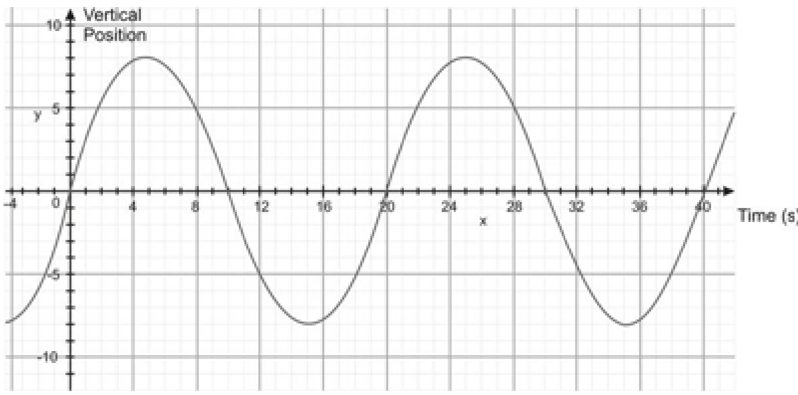
8. Below are a number of series of waves. Underneath each diagram write the numbers of wavelengths in the series.



________ ________ ________ ________

9. Reread the differences between transverse and longitudinal waves. For each of the following types of waves, tell what type it is and why. (Include a sketch for each.)

10. A mass is oscillating up and down on a spring. Below is a graph of its vertical position, in cm, as a function of time.



Determine the

a. amplitude

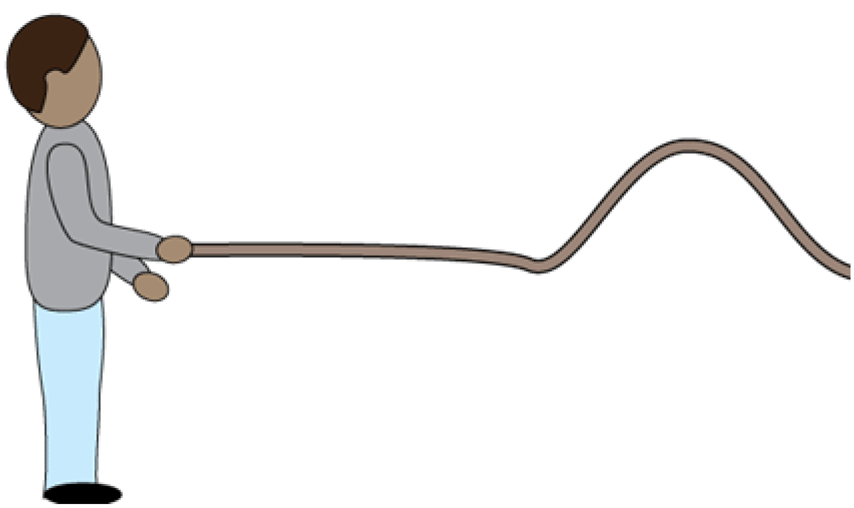
b. period

c. frequency

d. At what times is the mass momentarily at rest? How do you know?

How are speed, wavelength, and frequency related?

Assume that you move one end of a rope up and down just once to generate a wave in the rope. How long will take the wave to travel down the rope to the other end? It depends on the length of the rope and the speed of the wave.



The Speed of a Wave

Wave speed is the distance a wave travels in a given amount of time, such as the number of meters it travels per second. Wave speed can be represented by the equation:

$$Speed = \frac{distance}{time} = \frac{wavelength}{period} = \frac{\lambda}{T}$$

Wave Speed, Wavelength, and Wave Frequency

Sometimes it is more useful to write the equation in terms of frequency instead of period, using the relationship $T = \frac{1}{f}$. Wave speed is related to both wavelength and wave frequency. **Wavelength** is the distance between two corresponding points on adjacent waves. Wave **frequency** is the number of waves that pass a fixed point in a given amount of time. This equation shows how the three factors are related:

$$\text{Wave speed} = \text{wavelength x frequency}$$

$$v = \lambda f$$

In this equation, wavelength is measured in meters and frequency is measured in hertz (Hz), or number of waves per second. Therefore, wave speed is given in meters per second, which is the SI unit for speed.

Q: If you increase the wavelength of a wave, does the speed of the wave increase as well?

A: Increasing the wavelength of a wave doesn't change its speed. That's because when wavelength increases, wave frequency decreases. As a result, the product of wavelength and wave frequency is still the same speed. The speed is dependent on the wave medium.

At the following URL, you can see what happens to the wavelength when the frequency of a wave increases. http://go.uen.org/b3X

What are reflection, refraction, and diffraction?

Have you ever heard an echo of your own voice? An echo occurs when sound waves bounce back from a surface that they can't pass through. The girl pictured here is trying to create an echo by shouting toward a large building. When the sound waves strike the wall of the building, most of them bounce back toward the girl, and she hears an echo of her voice. An echo is just one example of how waves interact with matter.

How Waves Interact with Matter

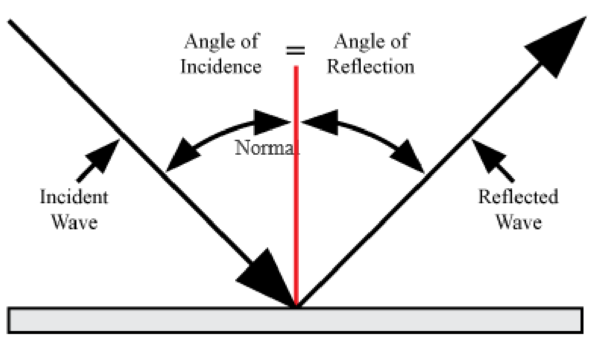
Waves interact with matter in several ways. The interactions occur when waves pass from one medium to another. The types of interactions are reflection, refraction, and diffraction. Each type of interaction is described in detail below.

You can see animations of the three types at this [URL: http://go.uen.org/b3Y](http://go.uen.org/b3Y)

Reflection

An echo is an example of wave reflection. Reflection occurs when waves bounce back from a boundary that separates two different mediums. Reflection can happen with any type of waves, not just sound waves. For example, light waves can also be reflected. In fact, that's how we see most objects. Light from a light source, such as the sun or a light bulb, shines on the object and some of the light is reflected. When the reflected light enters our eyes, we can see the object.

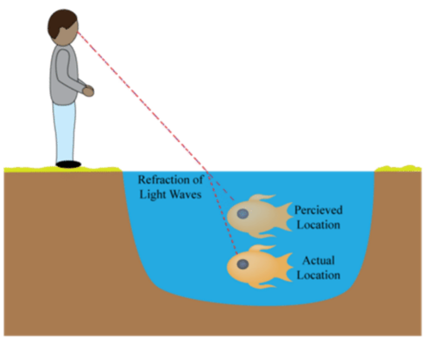
Reflected waves have the same speed and frequency as the original waves before they were reflected because they do not change the medium. However, the direction of the reflected waves is different. When waves strike an obstacle head on, the reflected waves bounce straight back in the direction they came from. When waves strike an obstacle at any other angle, they bounce back at the same angle but in a different direction. This is illustrated in diagram. In this diagram, waves strike a wall at an angle, called the angle of incidence. The waves are reflected at the same angle, called the angle of reflection, but in a different direction. Notice that both angles are measured relative to a line that is perpendicular to the wall. This line is called the normal line.



Refraction

Refraction is another way that waves interact with matter. Refraction occurs when waves bend as they enter a new medium at an angle. You can see an example of refraction in the picture. Light bends when it passes from air to water or from water to air. The bending of the light traveling from the fish to the man's eyes causes the fish to appear to be in a different place from where it actually is.

Waves bend as they enter a new medium because they start traveling at a different speed in the new medium. For example, light travels more slowly in water than in air. This causes it to refract when it passes from air to water or from water to air.

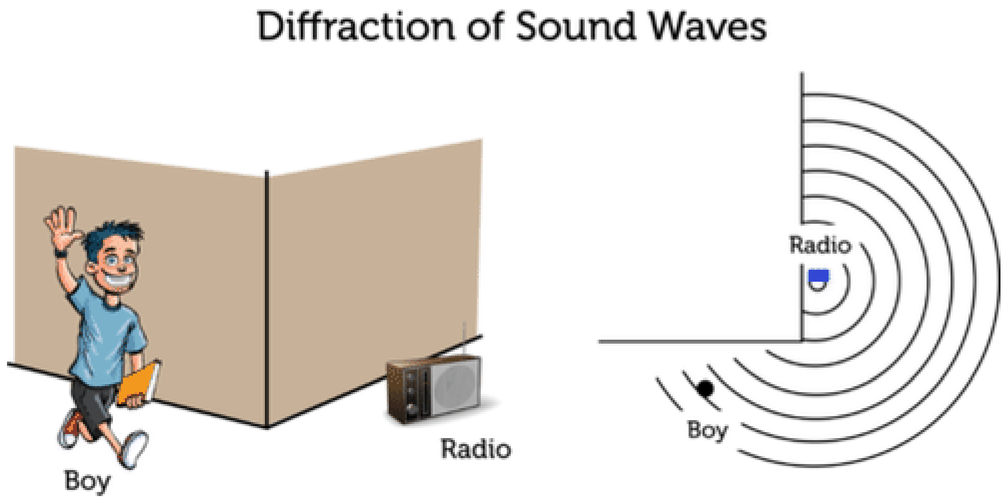


Q: Where would the fish appear to be if the man looked down at it from straight above its actual location?

A: The fish would appear to be where it actually is because refraction occurs only when waves (in this case light waves from the fish) enter a new medium at an angle other than to the normal.

Diffraction

Did you ever notice that you can hear sounds around the corners of buildings even though you can't see around them? The figure shows why this happens. As you can see from the figure, sound waves spread out and travel around obstacles. This is called diffraction. It also occurs when waves pass through an opening in an obstacle. All waves may be diffracted, but it is more pronounced in some types of waves than others. For example, sound waves bend around corners much more than light does. That's why you can hear but not see around corners.



For a given type of wave, such as sound waves, how much the waves diffract depends on the size of the obstacle (or opening in the obstacle) and the wavelength of the waves. In the figure, there is a small opening for the sound waves coming from radio. This small opening allows a small amount diffraction to happen and the sound can now be heard around the corner by the boy. Note that the wavelength of the wave is the distance between the vertical lines.

For an interactive animation of a diagram like the one above, go to the following URL:

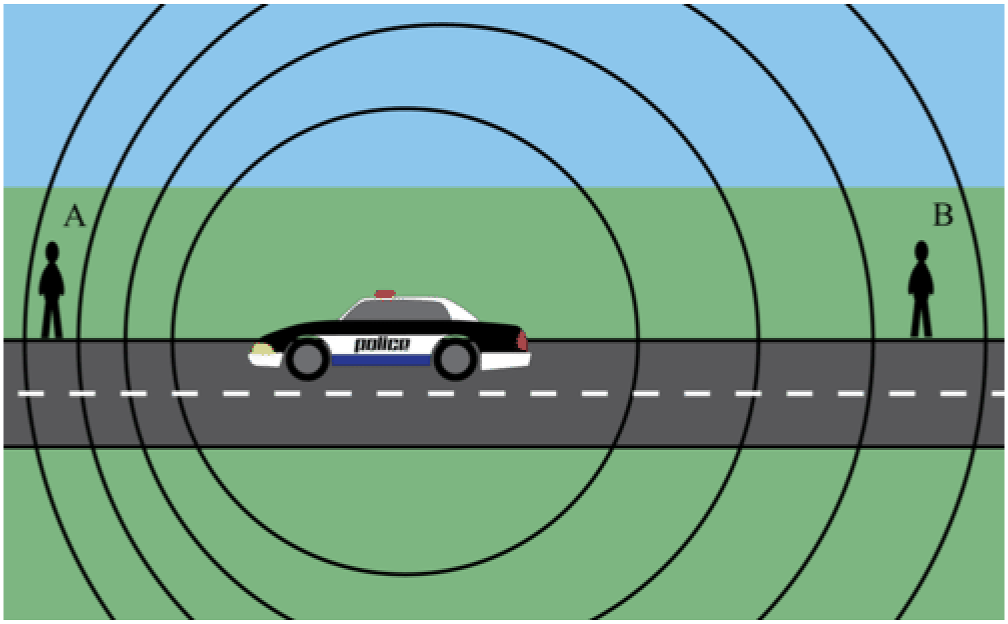
- http://go.uen.org/b3Z

What is the Doppler Effect?

Has this ever happened to you? You hear a siren from a few blocks away. The source is a police car that is racing in your direction. As the car approaches, zooms past you, and then speeds off into the distance, the sound of its siren keeps changing in pitch. First the siren gets higher in pitch, and then it suddenly gets lower. Do you know why this happens? The answer is the Doppler Effect.

What Is the Doppler Effect?

The Doppler Effect is a change in the frequency of waves that occurs when the source of the wave is moving relative to a stationary observer. (It can also occur when the source is stationary and the observer is moving.) The diagram shows how the Doppler Effect occurs.



The sound waves from the police car siren travel outward in all directions. Because the car is racing forward (to the left), the sound waves get bunched up in front of the car and spread out behind it. As they propagate outward they retain their circular shape. Sound waves that are closer together have a higher frequency, and sound waves that are farther apart have a lower frequency. The frequency of sound waves, in turn, determines the pitch of the sound. Sound waves with a higher frequency produce sound with a higher pitch, and sound waves with a lower frequency produce sound with a lower pitch.

For an animation of a diagram like the one above, go to the following URL:

- http://go.uen.org/b40

Experiencing the Doppler Effect

As the car approaches listener A, the sound waves appear closer together, increasing their frequency. This listener hears the higher pitch of the siren. As the car speeds away from listener B, the sound waves get farther apart, decreasing their frequency. This listener hears a lower pitch of the siren.

You can experience the Doppler Effect with a moving siren in the following animation:

- http://go.uen.org/b42

Q: What will the siren sound like to listener A after the police car passes him?

A: The siren will suddenly get lower in pitch because the sound waves will be much more spread out and have a lower frequency.

Check Your Understanding

At the following URL, observe the Doppler Effect in the animation and then answer the question. Check your answer by reading the “Discussion” section of the Web page.

- http://go.uen.org/b44

11. Define the Doppler Effect

12. Explain why the Doppler Effect occurs.

13. Does the siren of a moving police car seem to change pitch to the police officers inside the car? Why or why not?

Answers to Check Your Understanding

1. In a transverse wave the particles move perpendicular to the propagation of the wave. In the longitudinal wave the particles move parallel to the propagation of the wave.

2. Answers will vary, but may include:

a. Transverse: Phone cord, rope, string instruments

b. Longitudinal: Slinky, Sound

3. a. Crest
   b. Trough

4. a. Crest
   b. Wavelength
   c. Amplitude
   d. Trough
   e. Amplitude
   f. Wavelength
   g. Resting Position

5. Energy

6. Amplitude

7. Wavelength

8. a. 1 ½ wavelengths

b. 1 wavelength

c. 2 ½ wavelengths

d. ½ wavelength

9. a. Longitudinal, sound compresses the air molecules to move. (Sketches will vary)

b. Transverse, because the string moves perpendicular to the motion of the vibration. (Sketches will vary)

c. Transverse, because the surface of the drum moves up and down. (Sketches will vary)

10.

a. 8 cm

b. 20 s

c. $$f = \frac{1}{T} = \frac{1}{20\ s} = 0.05\ Hz$$

d. At the peak and trough the slope of the tangent line on the position vs. time graph is 0, so the velocity is 0 cm/s.

11. The change in the frequency of a wave due to the motion of the source of the observer of the wave.

12. It occurs because of a change in the wavelength of the wave due to the motion of the source or the observer.

13. The pitch does not change because the police officers are not moving relative to the wave.

5.2 What is an Electromagnetic Wave?

Objectives

- Describe the relationship of energy to **wavelength** or **frequency** for electromagnetic radiation.
- Distinguish between the different parts of the **electromagnetic spectrum** (e.g. **radio waves** and **x-rays** or **visible light** and **microwaves**).
- Explain that the different parts of the electromagnetic spectrum all travel through empty space and at the same speed.
- Explain the observed change in frequency of an electromagnetic wave coming from a moving object as it approaches and moves away (i.e. **Doppler effect**, red/blue shift).
- Provide examples of the use of electromagnetic radiation in everyday life (e.g. communications, lasers, microwaves, cellular phones, satellite dishes, **visible light)**.

Did you ever wonder how a microwave works? It directs invisible waves of radiation toward the food placed inside of it. The radiation transfers energy to the food, causing it to get warmer. The radiation is in the form of microwaves, which are a type of electromagnetic waves.

How are electromagnetic waves made?

Electromagnetic waves are waves that consist of vibrating electric and magnetic fields. Like other waves, electromagnetic waves transfer energy from one place to another. The transfer of energy by electromagnetic waves is called electromagnetic radiation. Electromagnetic waves can transfer energy through matter or across empty space.

For an excellent video introduction to electromagnetic waves, go to this URL:

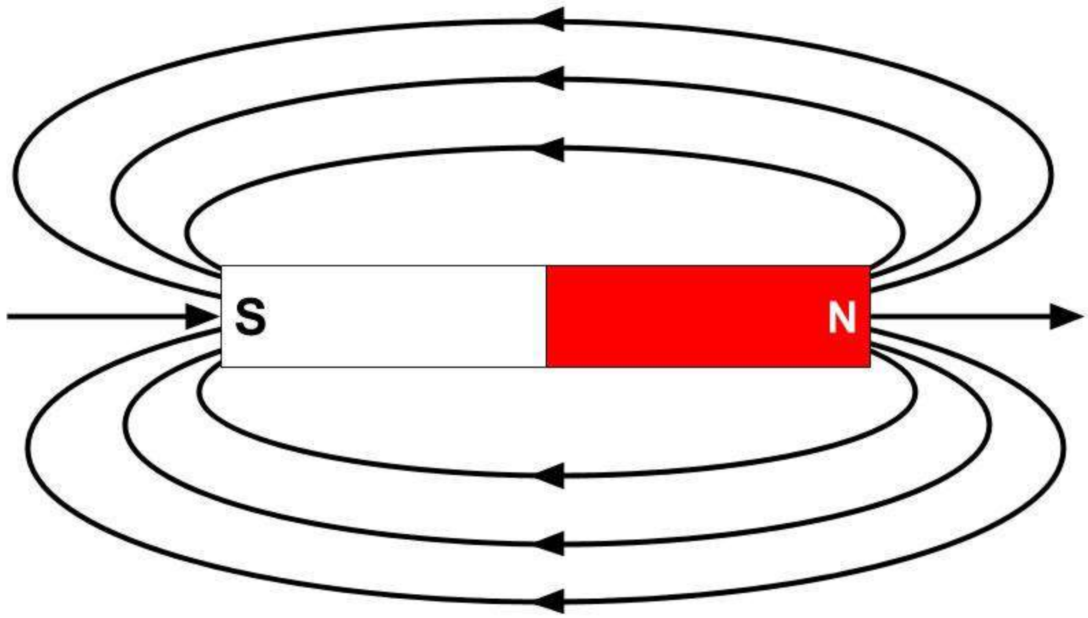
- http://go.uen.org/b45

May the Force Be with You

A familiar example may help you understand the vibrating electric and magnetic fields that make up electromagnetic waves. Consider a bar magnet, like the one in the figure

below. The magnet exerts magnetic force over an area all around it. This area is called a magnetic field. The field lines in the diagram represent the direction and location of the magnetic force. Because of the field surrounding a magnet, it can exert force on objects without touching them. They just have to be within its magnetic field.

Q: How could you demonstrate that a magnet can exert force on objects without touching them?

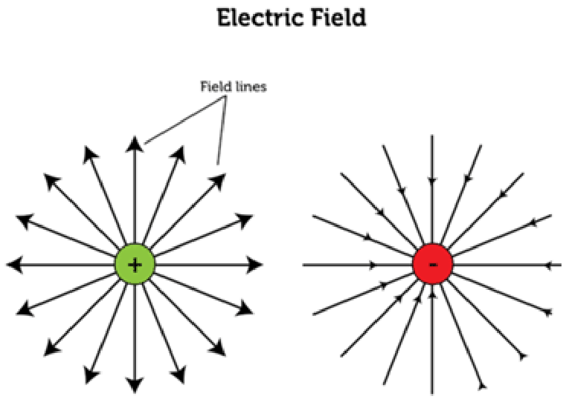


Field Lines Around a Bar Magnet

A: You could put small objects containing iron, such as paper clips, near a magnet and show that they move toward the magnet.

An electric field is similar to a magnetic field. It is an area of electrical force surrounding a positively or negatively charged particle. You can see electric fields in the following Figure below. Like a magnetic field, an electric field can exert force on objects over a distance without actually touching them.

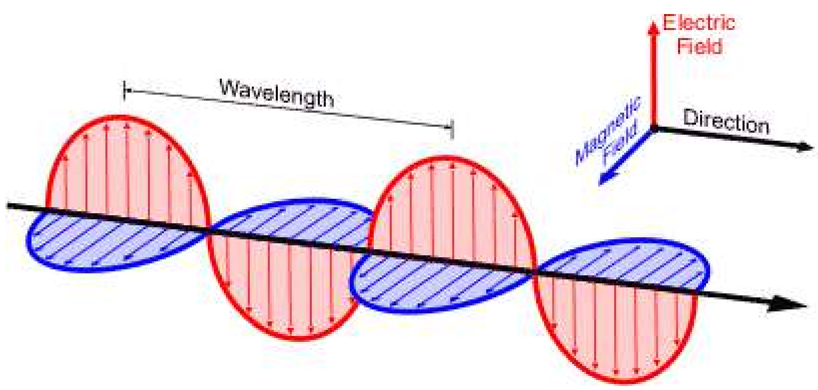
How an Electromagnetic Wave Begins



An electromagnetic wave begins when an electrically charged particle vibrates. A vibrating charged particle causes the electric field surrounding it to vibrate as well. A vibrating electric field, in turn, creates a vibrating magnetic field. The two types of vibrating fields combine to create an electromagnetic wave.

You can see animations of electromagnetic waves at these URLs:

- http://go.uen.org/b46



How an Electromagnetic Wave Travels

As you can see in the diagram, the electric and magnetic fields that make up an electromagnetic wave are perpendicular (at right angles) to each other. Both fields are also perpendicular to the direction that the wave travels. Therefore, an electromagnetic wave is a transverse wave. However, unlike a mechanical transverse wave, which can only travel through matter, an electromagnetic transverse wave can travel through empty space. When waves travel through matter, they lose some energy to the matter as they pass through it. But when electromagnetic waves travel through space, no energy is lost. Therefore, electromagnetic waves don’t get weaker as they travel. However, the energy is “diluted” as it travels farther from its source because it spreads out over an ever-larger area.

Electromagnetic Wave Interactions

When electromagnetic waves strike matter, they may interact with it in the same ways that mechanical waves interact with matter. Electromagnetic waves may:

- Reflect - bounce back from a surface;
- Refract - bend when entering a new medium;
- Diffract - spread out around obstacles or through openings.

Electromagnetic waves may also be absorbed by matter and converted to other forms of energy. Microwaves are a familiar example. When microwaves strike food in a microwave oven, they are absorbed and converted to thermal energy, which heats the food.

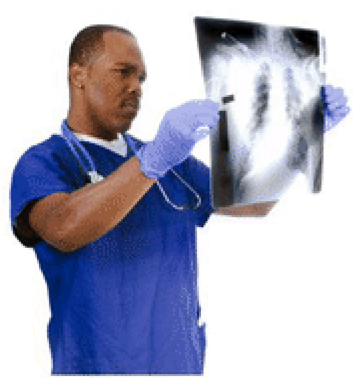
Sources of Electromagnetic Waves

- The most important source of electromagnetic waves on Earth is the Sun.
- Electromagnetic waves travel from the Sun to Earth across space and provide virtually all the energy that supports life on our planet. Many other sources of electromagnetic waves depend on technology. Radio waves, microwaves, and x rays are examples. We use these electromagnetic waves for communications, cooking, medicine, and many other purposes.

Check Your Understanding

1. List three sources of electromagnetic waves on Earth.

How fast do EM waves travel?



What do these two photos have in common? They both represent electromagnetic waves. These are waves that consist of vibrating electric and magnetic fields. They transmit energy through matter or across space. Some electromagnetic waves are generally harmless. The light we use to see is a good example. Other electromagnetic waves can be very harmful and care must be taken to avoid too much exposure to them. X rays are a familiar example. Why do electromagnetic waves vary in these ways? It depends on their properties. Like other waves, electromagnetic waves have properties of speed, wavelength, and frequency.

Speed of Electromagnetic Waves

All electromagnetic waves travel at the same speed through empty space. That speed, called the speed of light, is about 300 million meters per second (3.0×10^8 m/s). Nothing else in the universe is known to travel this fast. The sun is about 150 million kilometers (93 million miles) from Earth, but it takes electromagnetic radiation only 8 minutes to reach Earth from the sun. If you could move that fast, you would be able to travel around Earth 7.5 times in just 1 second!

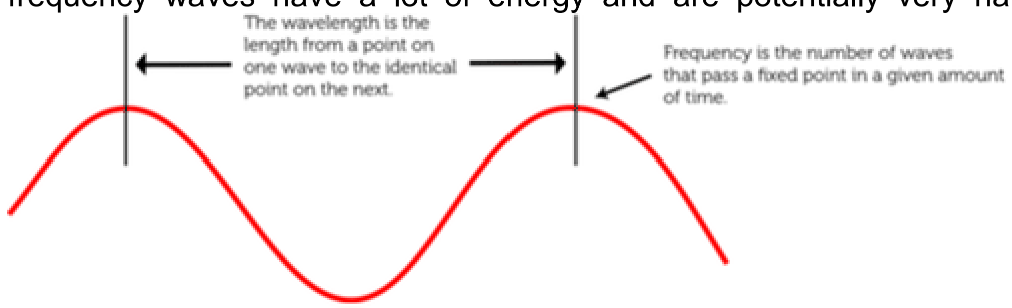
You can learn more about the speed of light at this URL:

- http://go.uen.org/b47

Wavelength and Frequency of Electromagnetic Waves

Although all electromagnetic waves travel at the same speed across space, they may differ in their wavelengths, frequencies, and energy levels.

- Wavelength is the distance between corresponding points of adjacent waves (see the Figure below). Wavelengths of electromagnetic waves range from longer than a soccer field to shorter than the diameter of an atom.
- Wave frequency is the number of waves that pass a fixed point in a given amount of time. Frequencies of electromagnetic waves range from thousands of waves per second to trillions of waves per second.
- The energy of electromagnetic waves depends on their frequency. Low-frequency waves have less energy and are normally harmless. High-frequency waves have a lot of energy and are potentially very harmful.



Q: Which electromagnetic waves have higher frequencies: visible light or X rays?

A: X rays can be harmful but visible light is harmless, so you can infer that X rays have higher frequencies than visible light.

Speed, Wavelength, and Frequency

The speed of a wave is a product of its wavelength and frequency. Because all electromagnetic waves travel at the same speed through space, a wave with a shorter wavelength must have a higher frequency, and vice versa. This relationship is represented by the equation:

Wave speed=wavelength x frequency

$$|v| = \lambda f$$

Therefore, if either wavelength or frequency is known, the missing value can be calculated since we always know the speed of the wave. Consider an electromagnetic wave that has a wavelength of 3 meters. Its speed, like the speed of all electromagnetic waves, is 3.0×10^8 meters per second. Its frequency can be found by substituting these values into the frequency equation:

$$f = \frac{|v|}{\lambda}$$

$$f = \frac{3x10^8\ m/s}{3m} = 1x10^8\ Hz$$

Q: What is the wavelength of an electromagnetic wave that has a frequency of 3.0×10^8 Hz?

A: Use the wavelength equation:

$$\text{Wavelength} = \frac{3.0\ x\ 10^8\ m/s}{3.0\ x\ 10^8\ waves/se} = 1.0\ m$$

You can learn more about calculating the frequency and wavelength of electromagnetic waves at these URLs:

- http://go.uen.org/b48
- http://go.uen.org/b49

Key Equations

$c = \lambda f$	wave equation for light
$c\ =\ 3\ x\ 10^8\ m/s$	the speed of light in a vacuum

Check Your Understanding

2. Use the calculator at the following URL to find the frequency and energy of electromagnetic waves with different wavelengths. Use at least eight values for wavelength. Record and make a table of the results. http://go.uen.org/b4a

3. What is the speed of light across space?

4. How is the energy of an electromagnetic wave related to its frequency?

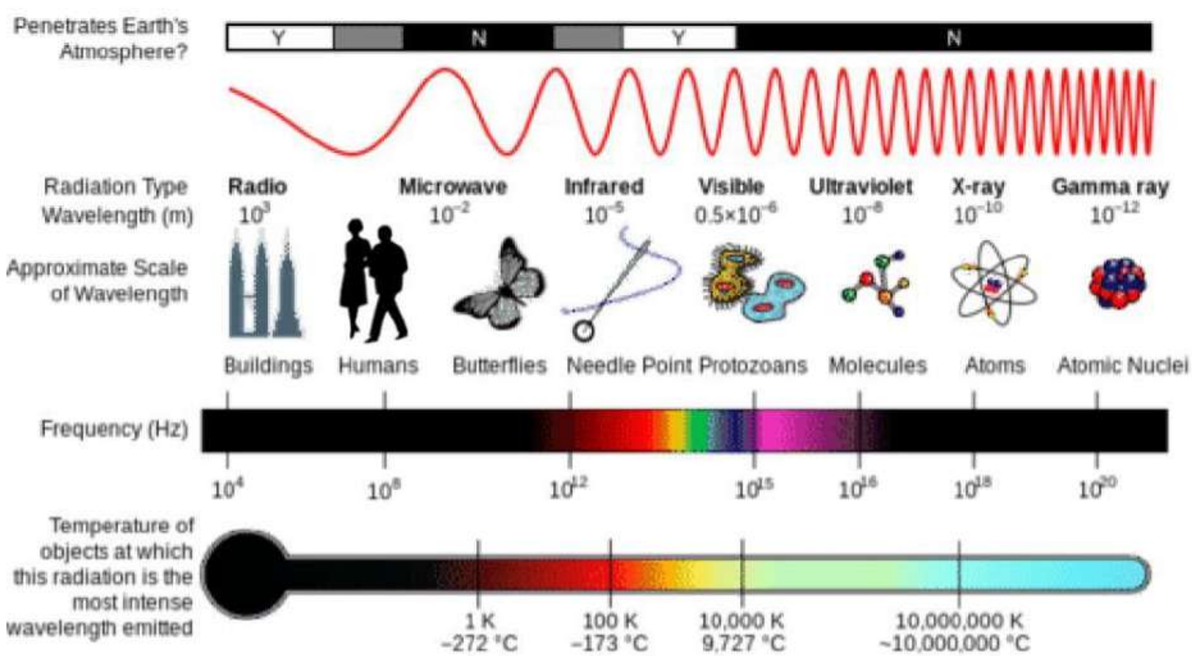
5. If the frequency of an electromagnetic wave is 6×10^8 Hz, what is its wavelength?

What is the EM spectrum?

Electromagnetic (EM) waves are classified by their frequency and wavelength. EM waves with a high frequency also have a short wavelength. EM waves with a low frequency have a long wavelength. Energy is directly related to the frequency of a wave. The higher the frequency, the more energy the wave has. Radio waves have a very low frequency and therefore a low energy. Gamma rays have a high frequency and a high energy.

Visible light (the part of the EM spectrum that we see) is a very small portion of the EM spectrum. Red has the lowest frequency and longest wavelength of the light that humans can see. Violet light has the highest frequency of visible light. EM waves that are have a slightly lower frequency than red are called infrared waves. EM waves with a slightly higher frequency than violet light are called ultraviolet waves.

The spectrum of electromagnetic radiation can be roughly broken into the following ranges:



To see the lighter side of ROYGBIV, a song by They Might Be Giants can be seen at the following URL:

- http://go.uen.org/b4b

In the table below, the parts of the **EM spectrum** are classified by their wavelengths.

EM wave	**Wavelength range**	**Comparison size**
gamma-ray (γ - ray)	10^{-11} m and shorter	atomic nucleus
x – ray	10^{-11} m−10^{-8} m	hydrogen atom
ultraviolet (UV)	10^{-8} m−10^{-7} m	small molecule
violet (visible)	∼4×10^{-7} m(400 nm)	typical molecule
blue (visible)	∼450 nm	typical molecule
green (visible)	∼500 nm	typical molecule
red (visible)	∼650 nm	typical molecule
infrared (IR)	10^{-6} m−1 mm	human hair
Microwave	1 mm−10 cm	human finger

Radio	Larger than 10 cm	car antenna

Q: Which has a higher frequency, green light or microwaves?

A: Green light has a higher frequency than microwaves. It is possible to calculate it, but since the speed of an electromagnetic wave is constant we know that waves with higher wavelengths must have a lower frequency based on the wave equation.

Sources of Electromagnetic Waves

- The most important source of electromagnetic waves on Earth is the Sun. Virtually all of the energy found on the Earth comes from our Sun. EM waves can come from many other sources, including other stars. EM waves also come from technology found on the Earth, such as Radio waves, cellular phones, lasers, and X-rays. Infrared waves also radiate from living things as heat is emitted. Electromagnetic waves are found all around us.

What is blueshift and redshift?

Blueshift and Redshift

Blueshift and redshift is simply another way to word the Doppler Effect for EM waves. Remember that the Doppler Effect is the observed change in the frequency of a wave when objects are in relative motion. Red-shift can occur when either the Earth is moving away from a distant star (or other object) or when the star is moving away from the Earth. Using equations for the Doppler Effect, scientists can determine the relative speeds of planets, stars, galaxies, and other celestial bodies in our universe.

A blue-shift is any decrease in wavelength (increase in frequency); the opposite effect is referred to as redshift. In visible light, this shifts the color from the red end of the spectrum to the blue end. The term also applies when photons outside the visible spectrum (e.g. x-rays and radio waves) are shifted toward shorter wavelengths. In physics (especially astrophysics), red-shift happens when the original wavelength of light seen coming from an object that has a relative velocity away from us is shifted towards the red end of the spectrum.

Q: If a far-away galaxy is moving away from the Earth, would it be experiencing red or blue shift?

A: Redshift

Check Your Understanding

6. Which type of EM waves have the highest energy?

7. When red-shift is occurring, does the frequency of the EM wave increase or decrease?

8. Suppose a microwave experienced blue-shift. What classification of wave could it be measured as now?

Answers to Check Your Understanding

1. Answers will vary, but may include:
   Light bulb, microwave, radio, x-ray machines

2. Answers will vary

3. 3×10^8 m/s

4. Energy is directly related to the frequency. The higher the frequency of a wave, the more energy the wave has.

5.

$$c = \lambda f$$

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8 \text{ m/s}}{6 \times 10^8 \text{ /s}} = 0.5 \text{ m}$$

6. Gamma Rays

7. Decrease

8. Infrared waves

Chapter 5 Summary

Vocabulary

- **Amplitude:** is the maximum distance the particles of the medium move from their resting positions when a wave passes through.
- **Blue-shift:** The observed increase in frequency of an EM wave caused when objects move toward each other.
- **Conduction:** the transfer of heat through direct contact.
- **Convection:** the transfer of heat through currents in a fluid.
- **Diffraction:** Bending of a wave around an obstacle or through an opening in an obstacle.
- **Doppler Effect:** Change in the frequency and pitch of sound that occurs when the source of the sound is moving relative to the listener.
- **Electromagnetic Radiation:** Transfer of energy by electromagnetic waves across space or through matter.
- **Electromagnetic spectrum:** the range of all types of electromagnetic radiation; the range of wavelengths or frequencies over which electromagnetic radiation extends.
- **Electromagnetic Wave:** Transverse wave consisting of vibrating electric and magnetic fields that can travel across space.
- **Frequency:** the number of waves that pass a fixed point in a given amount of time
- **Gamma ray:** A photon of electromagnetic radiation of very short wavelength, less than about 0.01 nanometer, and very high energy; can be used to treat cancer; studied by astronomers.
- **Infrared:** having a wavelength just greater than that of the red end of the visible light spectrum but less than that of microwaves. Infrared radiation have wavelengths from about 800 nm to 1 mm, and is emitted particularly by heated objects.
- **Mechanical wave:** is a disturbance in matter that transfers energy through the matter. There are three types: transverse, longitudinal, and surface waves.
- **Microwave:** an electromagnetic wave with a wavelength that ranges from 0.001–0.3 m, shorter than a normal radio wave but longer than those of infrared radiation. Microwaves are used in radar, in communications, and for heating in microwave ovens and in various industrial processes.
- **Period:** the amount of time for harmonic motion to repeat itself, or one full cycle, represented by *T.*
- **Radiation:** the transfer of energy through electromagnetic waves.
- **Radio wave:** an electromagnetic wave of a frequency between about 10^4 and 10^{11} or 10^{12} Hz, or larger than 10 cm; used for long-distance communication.

- **Red-shift:** The observed lowering in frequency of an EM wave caused when objects move away from each other.
- **Reflection:** Bouncing back of waves from a barrier they cannot pass through.
- **Refraction:** Bending of waves as they enter a new medium at an angle and change speed.
- **Speed of Light:** Speed at which all electromagnetic waves travel through space, which is 3.0×10^8 m/s.
- **Ultraviolet:** part of the electromagnetic spectrum having a wavelength shorter than that of the violet end of the visible spectrum but longer than that of X-rays. Wavelengths range from 10 nm to 400 nm.
- **Visible light:** part of the electromagnetic spectrum that can be detected by the human eye. The wavelengths associated with this range are 380 nm to 750 nm. (1 nm = 10-9m).
- **Wave:** an oscillation accompanied by a transfer of energy through a medium.
- **X-ray:** an electromagnetic wave with high energy and a very short wavelength, ranging from 0.01nm to 10 nm.

Summary

- A mechanical wave is a disturbance in matter that transfers energy through the matter.
- The matter through which a mechanical wave travels is called the medium (plural, media).
- There are three types of mechanical waves: transverse, longitudinal, and surface waves. They differ in how particles of the medium move when the energy of the wave passes through.
- Wave frequency (f) is the number of waves that pass a fixed point in a given amount of time.
- The SI unit for wave frequency is the hertz (Hz), where 1 hertz equals 1 wave passing a fixed point in 1 second.
- A higher frequency electromagnetic wave has more energy than a lower frequency electromagnetic wave.
- Three ways that waves may interact with matter are reflection, refraction, and diffraction.
- Reflection occurs when waves bounce back from a surface boundary that separates two different mediums.
- Refraction occurs when waves bend as they enter a new medium at an angle and start traveling at a different speed.
- Diffraction occurs when waves spread out as they travel around obstacles or through openings in obstacles in the same medium.
- The Doppler Effect is a change in the frequency of sound waves that occurs when the source of the sound waves is moving relative to a stationary listener.
- As the source of sound waves approaches a listener, the sound waves get closer together, increasing their frequency and the pitch of the sound. The opposite happens when the source of sound waves moves away from the listener.

- Electromagnetic waves are waves that consist of vibrating electric and magnetic fields. They transfer energy through matter or across space. The transfer of energy by electromagnetic waves is called electromagnetic radiation.
- The electric and magnetic fields of an electromagnetic wave are areas of electric force or magnetic force. The fields can exert force on objects over a distance.
- An electromagnetic wave begins when an electrically charged particle vibrates. This causes a vibrating electric field, which in turn creates a vibrating magnetic field. The two vibrating fields together form an electromagnetic wave.
- An electromagnetic wave is a transverse wave that can travel across space as well as through matter. When it travels through space, it doesn't lose energy to a medium as a mechanical wave does.
- When electromagnetic waves strike matter, they may be reflected, refracted, or diffracted. Or they may be absorbed by matter and converted to other forms of energy.
- The most important source of electromagnetic waves on Earth is the Sun. Many other sources of electromagnetic waves depend on technology.
- All electromagnetic waves travel across space at the speed of light, which is about 300 million meters per second (3.0×10^8 m/s).
- Electromagnetic waves vary in wavelength and frequency. Longer wavelength electromagnetic waves have lower frequencies, and shorter wavelength waves have higher frequencies. Higher frequency waves have more energy.
- The speed of a wave is a product of its wavelength and frequency. Because the speed of electromagnetic waves through space is constant, the wavelength or frequency of an electromagnetic wave can be calculated if the other value is known.

Online Interactive Activities

Simulation of a wave on a string:

Wave on a String PhET

- http://go.uen.org/b4c

Wave interference activity:

- http://go.uen.org/b4d
  or
- http://go.uen.org/b4e

CHAPTER 6

Physics with Technology Additions

This chapter is a supplement for those taking the CTE course Physics with Technology. It covers the Physics with Technology Performance Objectives that are not covered in the Utah Physics Core.

Chapter Outline

Physics with Technology Performance Objectives

3. Student correctly identifies and measures forces and calculate acceleration
   1. Create simple free body diagrams and identify the forces

2. Student measures and analyzes objects in linear or rotational motion.
   4. Describe Momentum

4. Student calculate and reports both energy and efficiency of a system.
   2. Calculate work in, work out, and efficiency

7. Student measures changes in thermal properties (heating or cooling).

1. Correctly use temperature measuring devices
2. Accurately record temperature data over time in a graph, table, or chart
3. Observe and record changes of state
4. Calculate heat flow and heat loss/gain

5. Student determines both voltage and current in circuits
    1. Diagram and analyze series and parallel circuits
    2. Calculate voltage in parallel circuits
    3. Calculate amperage in series circuits
    4. Correctly measure resistance, voltage, and amperage in circuits using a multimeter

6.1 Types of Forces and Free Body Diagrams (PwT 3.1)

Objectives

- Create simple free body diagrams and identify the forces

What are the different types of forces?

There are a number of different forces that exist in the world. The table below identifies common forces, describes them, and common symbols used to identify them.

Force	Description	Symbols
Weight	The force of gravity between an object at or near the surface of the earth. Pointed towards the center of the earth. Long range force. For more info see Section 4.1	w F_g
Tension	The force exerted by a string, wire, or rope pulling between two objects. Direction of tension is always parallel to the string, wire, or rope.	T F_T
Spring	The force exerted by a spring that is either compressed or stretched. Direction of spring force is always parallel to the spring	F_{sp}
Normal	The forces exerted by a surface against any object pressing against it. The Direction of the Normal is always perpendicular to the surface. Also known as the support force. For more info see Section 3.3	N F_N
Friction	The force which resists motion when two solid objects are in contact with one another. The direction is always opposite of the direction of motion and parallel to the surfaces involved. Two Types: • Static - when the objects are at rest • Kinetic - When the objects are moving relative to one another For more info see Section 3.3	F_f f_s f_k

Drag	The force which resists motion when an object moves through a fluid - liquid or gas. Also known as air resistance. The direction is always opposite of the direction of motion. The object has to be moving at a substantial speed for air drag to be significant	D F_D F_{AD}
Thrust	Caused when a rocket or jet expels gas at a high speed. The direction of thrust is in the opposite direction in which the exhaust gas is expelled.	T F_T
Electric & Magnetic Forces	Forces caused between stationary and moving charges. See Section 4.2 for more info about electric forces	F_E F_B, B

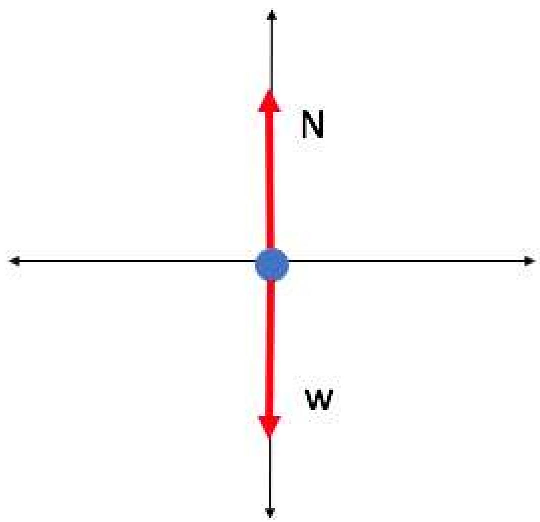
For more information on forces see Section 2.1

What is a free body diagram?

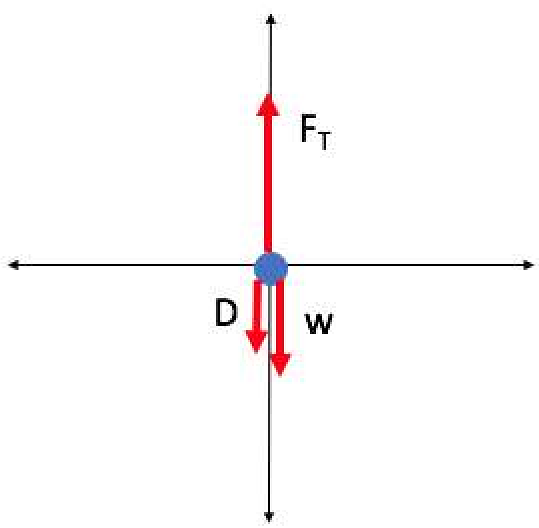
In physics, knowing how to draw a free body diagram (FBD) when solving problems involving forces can be essential before proceeding to the problem solving stage. The FBD allows one to visualize the situation and also to make sure all the forces are accounted. In addition, a very solid understanding of the physics is gleaned and many questions can be answered solely from the FBD.
The steps to creating a free body diagram are as follows:

1. Draw a coordinate system
2. Represent the object as dot at the center of the coordinate system
3. Identify all the forces acting on the object
4. Draw a vector representing each force acting on the object. Be sure to label each force.

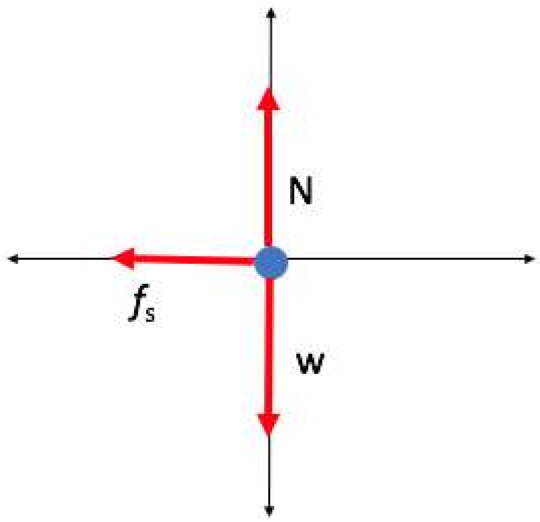
A free body diagram is very similar to vector diagrams described in Section 3.3. Below are some examples of free body diagrams.



A car sitting in the parking lot (CC Mary Lamoreaux)



A rocket accelerating into orbit (CC Mary Lamoreaux)



A box sliding to a stop (CC Mary Lamoreaux)

6.2 Momentum (PwT 2.4)

Objectives

- Describe Momentum

What is momentum?

Momentum is a vector that points in the direction of the velocity vector. The magnitude of this vector is the product of mass and speed. The total momentum of the universe is always the same and is equal to zero. The total momentum of an isolated system never changes. Momentum can be transferred from one body to another. In an isolated system in which momentum is transferred internally, the total initial momentum is the same as the total final momentum. Momentum conservation is especially important in collisions, where the total momentum just before the collision is the same as the total momentum after the collision.

Key Equations

$p=mv$ Momentum is equal to the object's mass multiplied by its velocity

Interactive Simulation

- http://go.uen.org/b4f
- http://go.uen.org/b4g bumper cars

6.3 Work and Efficiency (PwT 4.2)

Objectives

- Calculate work in, work out, and efficiency

What is work?

For some, the exciting part of a roller coaster is speeding down; for others it is the anticipation of climbing up. While the coaster is being towed up, it is having work done on it. The work done towing it to the top of the hill becomes potential energy stored in the coaster and that potential energy is converted to kinetic energy as the coaster runs down from the top of the hill to the bottom.

Work

The word **work** has both an everyday meaning and a specific scientific meaning. In the everyday use of the word, work would refer to anything which required a person to make an effort. In physics, however, work is defined as the force exerted on an object multiplied by the distance the object moves due to that force.

$$W=Fd$$

In the scientific definition of the word, if you push against an automobile with a force of 200 N for 3 minutes but the automobile does not move, then you have done no work. Multiplying 200 N times 0 meters yields zero work. If you are holding an object in your arms, the upward force you are exerting is equal to the object's weight. If you hold the object until your arms become very tired, you have still done no work because you did not move the object in the direction of the force. When you lift an object, you exert a force equal to the object's weight and the object moves due to that lifting force. If an object weighs 200. N and you lift it 1.50 meters, then your work is $W=Fd=(200.\ N)(1.50\ m)=300.\ N\ m$.

Example

A boy lifts a box of apples that weighs 185 N. The box is lifted a height of 0.800 m. How much work did the boy do?

$W=Fd=(185\ N)(0.800\ m)=148\ N\ m=148$ Joules

Work is done only if a force is exerted in the direction of motion. If the motion is perpendicular to the force, no work has been done. If the force is at an angle to the motion, then the component of the force in the direction of the motion is used to determine the work done.

What is efficiency?

This man is pushing heavy boxes on a dolly. If he were to push the boxes across the ground without the dolly, it would take a lot more force because he would have to overcome the sliding friction between the boxes and the ground. Using a dolly reduces the friction because rolling friction between the wheels and the ground is much less than sliding friction.

Machines and Friction

A dolly is a machine because it changes a force to make work easier. What is work? In physics, work is defined as the use of force to move an object over a distance. It is represented by the equation:

$$\text{Work} = \text{Force} \times \text{Distance}$$

All machines make work easier, but they don't increase the amount of work that is done. You can never get more work out of a machine than you put into it. In fact, a machine always does less work on an object than the user does on the machine. That's because a machine must use some of the work put into it to overcome friction. Friction is the force that opposes motion between any surfaces that are touching. All machines involve motion, so they all have friction. How much work is needed to overcome friction in a machine depends on the machine's efficiency.

Machine Efficiency

Efficiency is the percent of work put into a machine by the user (input work) that becomes work done by the machine (output work). The output work is always less than the input work because some of the input work is used to overcome friction. Therefore, efficiency is always less than 100 percent. The closer to 100 percent a machine's efficiency is, the better it is at reducing friction. Look at the ramp in the Figure below. A ramp is a type of simple machine called an inclined plane. It is easier to push the heavy piece of furniture up the ramp to the truck than to lift it straight up off the ground, but pushing the furniture over the surface of the ramp creates a lot of friction. Some of the force applied to moving the furniture must be used to overcome the friction with the ramp.

Calculating Efficiency

Efficiency can be calculated with the equation:

$$\text{Efficiency} = \frac{\text{Output work}}{\text{Input work}} \times 100\%$$

Consider a machine that puts out 6000 joules of work. To produce that much work from the machine requires the user to put in 8000 joules of work. To find the efficiency of the machine, substitute these values into the equation for efficiency:

$$6000 \text{ J}/8000 \text{ J} \times 100\% = 75\%$$

Resources

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Summary

- A machine always does less work on an object than the user does on the machine, because the machine must use some of the work to overcome friction.
- Efficiency is the percent of work put into a machine by the user (input work) that becomes work done by the machine (output work). It is a measure of how well a machine reduces friction.
- You can calculate the efficiency of a machine with this equation: $\text{Efficiency} = \text{Work}_{\text{Out}}/\text{Work}_{\text{in}} \times 100\%$

Check for Understanding

1. Why would it be more efficient to use a dolly to roll the furniture up the ramp?
2. Rani puts 7500 joules of work into pushing a box up a ramp, but only 6700 joules of work actually go into moving the box. The rest of the work overcomes friction between the box and the ramp. What is the efficiency of the ramp?

Answers to Check for Understanding

1. There would be less friction to overcome if you used a dolly because of the wheels. So the efficiency of the ramp would be greater with the dolly.
2. 6700 /J7500 J×100%=90%

Vocabulary

Efficiency - Measure of how well a machine reduces friction; calculated as the percent of input work that becomes output work.

6.4 Thermal Properties (PwT 7)

Objectives

- Correctly use temperature measuring devices
- Accurately record temperature data over time in a graph, table, or chart
- Observe and record changes of state
- Calculate heat flow and heat loss/gain

What is temperature?

When you go outside on a summer day it feels warm. When you go outside on a winter day it feels cold. The difference you feel is based off a difference in temperature. Temperature is a measurement of the average kinetic energy of moving particles of matter based off a standard. There are three temperature scales that are used in the US and science: Fahrenheit, Celsius, and Kelvin. To measure temperature we use thermometers.

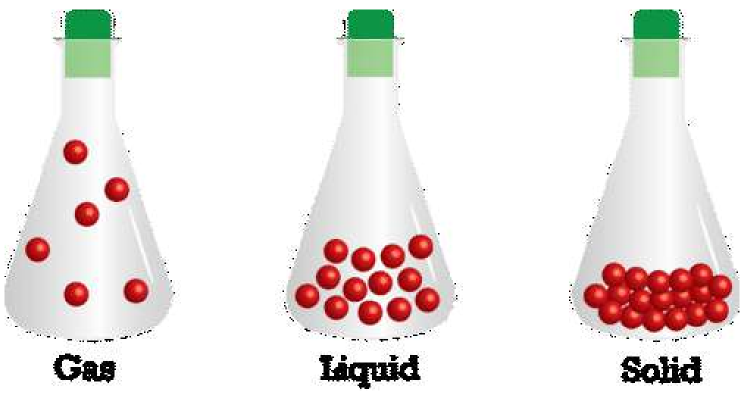
What are the different states of matter?

http://go.uen.org/b4i

Before the internal combustion engine was invented, steam engines were the power source for ships, locomotives, tractors, lumber saws, and most industrial machines. Coal or wood was burned to boil water into steam, which ran the engine.

Change of State

Most substances may exist in any of the three common states of matter. In the gaseous state, the molecular motion has completely overcome any attraction between the particles and the particles are totally separate from each other. There are large spaces between the particles and they move large distances between collisions. In the liquid state, the molecular motion and the molecular attractions are more balanced. While the particles stay more or less in contact with each other, they are still free to move and can slide past one another easily. In the solid state, the attractive forces dominate. The particles are pulled together into a tightly packed pattern which does not allow the particles to pass each other. The molecular motion in this form is essentially reduced to vibration in place. Increasing the temperature of a substance means increasing the molecular motion (kinetic energy) of the molecules in the substance. The phase in which a substance exists is the result of a competition between attractive forces and molecular motion.



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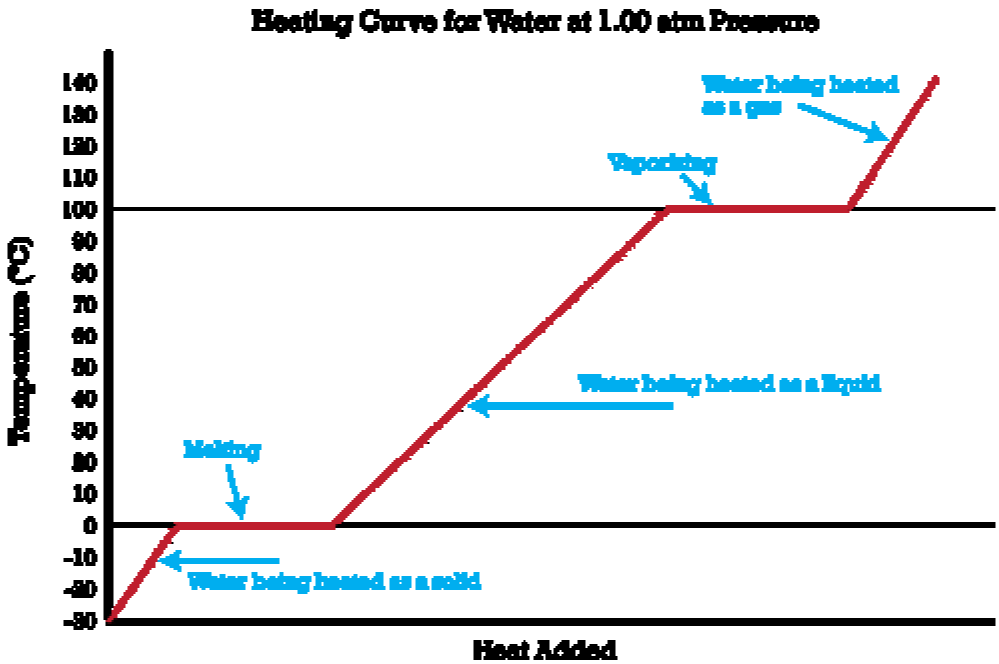
For most substances, when the temperature of the solid is raised high enough, the substance changes to a liquid, and when the temperature of the liquid is raised high enough, the substance changes to a gas. We typically visualize a solid as tiny particles in constant motion held together by attractive forces. As we add heat to the solid, the motion, or the kinetic energy, of the particles increases. At some temperature, the motion of the particles becomes great enough to overcome the attractive forces. The thermal energy that was added to the solid up to this point was absorbed by the solid as kinetic energy, increasing the speed of the molecules. The lowest temperature at which the particles are able to exist in the liquid form is called the melting point.

In order for the molecules to actually separate from each other, more energy must be added. This energy, called heat of fusion or heat of melting, is absorbed by the particles as potential energy as the solid changes to a liquid. Recognize that, once the temperature of a solid has been raised to the melting point, it is still necessary for the solid to absorb additional thermal energy in the form of potential energy as the molecules separate.

The boiling point of a liquid is the temperature at which the particles have sufficient molecular motion to exist in the form of a gas. Once again, however, in order for the particles to separate to the gaseous form, they must absorb a sufficient amount of potential energy. The amount of potential energy necessary for a phase change to gaseous form is called the heat of vaporization. Consider the heating curve shown below.



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The heating curve shown is for water but other substances have similarly shaped heating curves. Suppose you begin with solid water (ice) at -30°C and add heat at a constant rate. The heat you add in the beginning will be absorbed as kinetic energy and the temperature of the solid will increase. When you reach a temperature of 0°C (the melting point for water), the heat you add is no longer absorbed as kinetic energy. Instead, the added heat is absorbed as potential energy and the particles separate from each other. During the flat part of the curve labeled “melting”, heat is being added constantly but the temperature does not increase. At the left edge of this flat line, the water is solid; by the time enough heat has been added to get to the right edge, the water is liquid, but maintains the same temperature. Once all the water is in the liquid form, the added heat will once again be absorbed as kinetic energy and the temperature will increase again. During the time labeled “water being heated as a liquid”, all the added heat is absorbed as kinetic energy.

When a temperature of 100°C (the boiling point of water) is reached, the added heat is once again absorbed as potential energy and the molecules separate from liquid form into gaseous form. When all the substance has been converted into gas, the temperature will again begin to rise.

What is heat?

This chef is taking corn bread out of a hot oven. What happened to the batter when it was put in the oven? Did the hot oven add "heat energy" to the batter? Not exactly. Contrary to popular belief, heat is not a form of energy.

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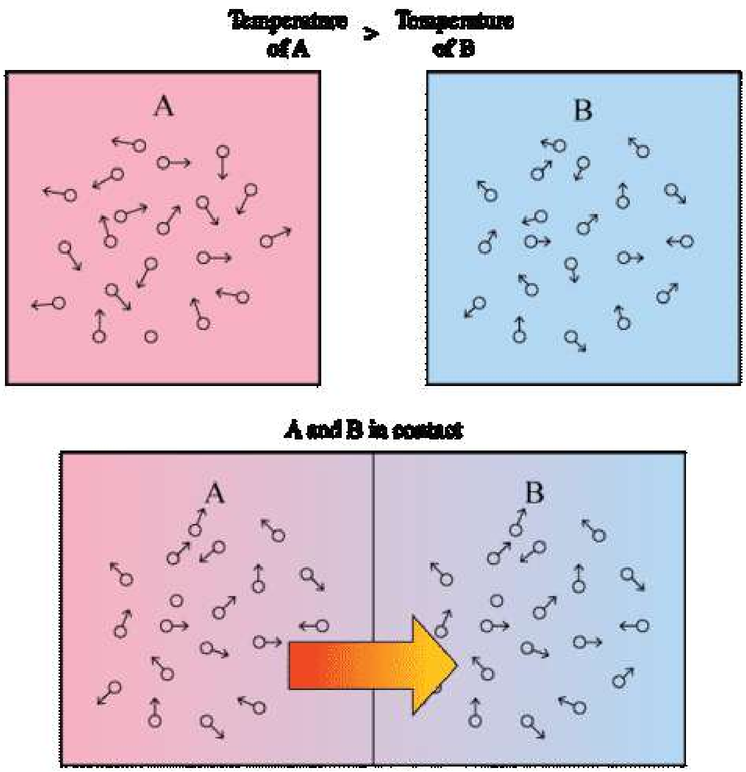
Heat

Heat is the transfer of thermal energy between substances. Thermal energy is the kinetic energy of moving particles of matter, measured by their temperature. Thermal energy always moves from matter with greater thermal energy to matter with less thermal energy, so it moves from warmer to cooler substances. You can see this in the Figure below. Faster-moving particles of the warmer substance bump into and transfer some of their energy to slower-moving particles of the cooler substance. Thermal energy is transferred in this way until both substances have the same thermal energy and temperature.



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Cooling Down by Heating Up

How do you cool down a glass of room-temperature cola? You probably add ice cubes to it, as in the Figure below. You might think that the ice cools down the cola, but in fact, it works the other way around. The warm cola heats up the ice. Thermal energy from the warm cola is transferred to the much colder ice, causing it to melt. The cola loses thermal energy in the process, so its temperature falls.

http://go.uen.org/b4l

How do you calculate heat and heat flow?

This image is of the Beehive Geyser in Yellowstone National Park. Underground water is heated by the earth's molten core and, when sufficient pressure is built up, the water shoots out of the ground in an amazing display.

Specific Heat

When heat flows into an object, its thermal energy increases and so does its temperature. The amount of temperature increase depends on three things: 1) how much heat was added, 2) the size of the object, and 3) the material of which the object is made. When you add the same amount of heat to the same mass of different substances, the amount of temperature increase is different. Each substance has a **specific heat,** which is the amount of heat necessary to raise one mass unit of that substance by one temperature unit.

In the SI system, specific heat is measured in J/g•°C. (Occasionally, you may also see specific heat expressed sometimes in J/kg•°C). The specific heat of aluminum is 0.903 J/g•°C. Therefore, it requires 0.903 J to raise 1.00 g of aluminum by 1.00 °C.

Specific Heat of Some Common Substances	
Material	**Specific Heat (J/g•°C)**
Aluminum	0.903
Brass	0.376

Carbon	0.710
Copper	0.385
Glass	0.664
Ice	2.060
Lead	0.130
Methanol	2.450
Water Vapor	2.020
Water (liquid)	4.180
Zinc	0.388

The amount of heat gained or lost by an object when its temperature changes can be calculated by the formula

$$Q=mc\Delta T$$

where Q is the heat gained or lost, m is the mass of the object, c is its specific heat, and ΔT is the change in temperature. You should note that the size of a Celsius degree and a Kelvin degree are exactly the same, and therefore ΔT is the same whether measured in Celsius or Kelvin.

To measure the rate of heat flow during a temperature change the following formula may be used:

$$\dot{Q}=\frac{Q}{t}$$

where $\dot{Q} = \frac{Q}{\Delta t}$ the rate of heat flow, Q is is the heat gained or lost, and Δt is the time for which the temperature change occurred.

Example

A 0.500 kg block of zinc is heated from 22 °C to 77 °C over a period of 10 min. How much heat was absorbed by the zinc? What is the rate of heat flow?

Q = mcΔT = (500 g)(0.388 J/g·°C)(22 °C−22 °C) = 10,600 J

$\dot{Q} = \frac{Q}{\Delta t}$ = Q/Δt = (10,600 J)/(600 sec) = 17.667 Watts

6.5 Circuits (PwT 5)

Objectives

- Diagram and analyze series and parallel circuits
- Calculate voltage in parallel circuits
- Calculate amperage in series circuits
- Correctly measure resistance, voltage, and amperage in circuits using a multimeter

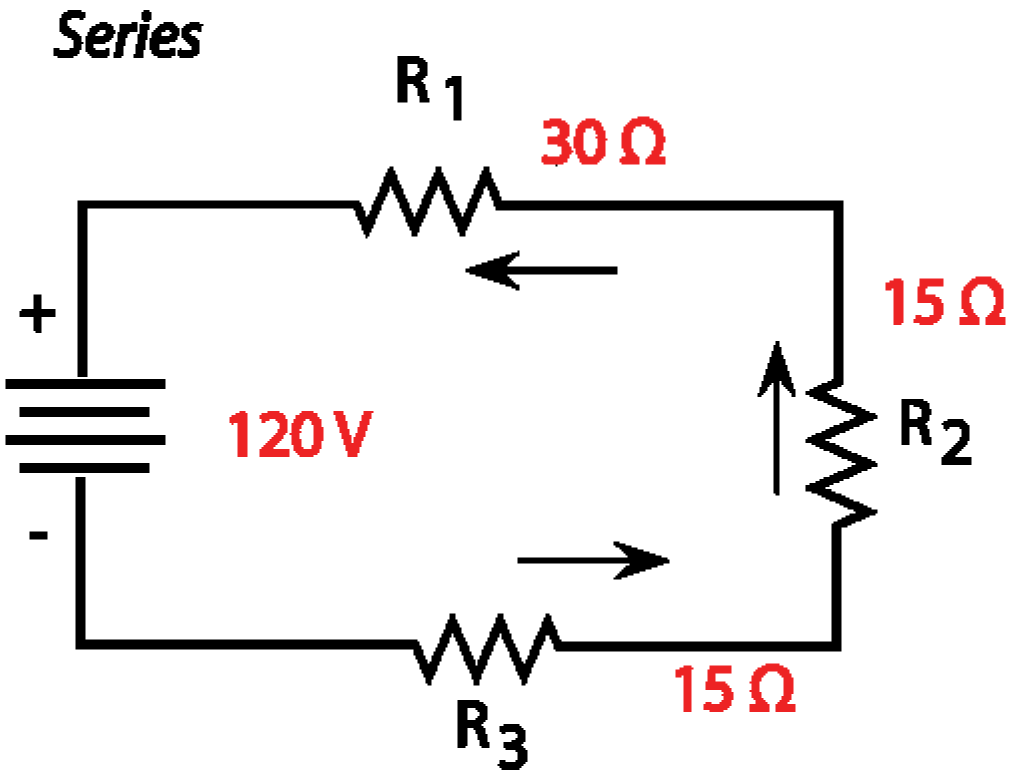
What is a circuit?

What are the characteristics of circuits?

Series Circuits

Electrical circuits are often modeled by using water in a river. The potential energy of the water is the highest at the source of the river and decreases as the water flows down the river toward the end. When the water reaches the ocean, its potential energy has become zero. The circuit shown below has a similar situation. The current in this circuit is drawn in the direction of the electron flow. It starts at the battery on the left, where

electrons leave the negative terminal and travel around the circuit. Since all of the current travels across each resistor, these resistors are said to be in **series**. A series circuit is one in which all of the current must pass through every resistor in the circuit. Returning to the water analogy, there is only one riverbed from the top of the mountain to the ocean.



Credit: Samantha Bacic
Source: CK-12 Foundation
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Consider the series circuit sketched above. This circuit has a voltage drop for the entire circuit of 120 V and has three resistors connected in series. The current in this circuit is drawn in terms of electron flow. The electrons leave the potential difference source at the negative terminal and flow through the three resistors, starting with R_3. Though they have a small amount of resistance, the resistance of the connecting wires is so small in relation to the resistors that we ignore it. Therefore, we say that there is no voltage drop when the current passes through the connecting wires. The voltage drops occur when the current passes through each of the resistors and the total voltage drop for the entire circuit is equal to the sum of the voltage drops through the three resistors.

$$V_T=V_1+V_2+V_3$$

The current through each of the resistors must be exactly the same because the current in a series circuit is the same everywhere. The current is moving in the entire circuit at the same time.

$$I_T=I_1=I_2=I_3$$

Since the current passes through each resistor, the total resistance in the circuit is equal to the sum of the resistors. In the circuit above, the total resistance is:

$$R_T=R_1+R_2+R_3$$

$$R_T=30\ \Omega+15\ \Omega+15\ \Omega=60\ \Omega$$

Therefore, the total current and the current through each resistor is

$$V=IR=120\ \text{V}$$

$$60\ \Omega=2.0\ A$$

The individual voltage drops can be calculated using the current through each resistor and each resistors' individual resistance.

$V_1=I_1R_1=(2.0\ A)(30\ \Omega)=60\ V$
$V_2=I_2R_2=(2.0\ A)(15\ \Omega)=30\ V$
$V_3=I_3R_3=(2.0\ A)(15\ \Omega)=30\ V$

Example

Four 15 Ω resistors are connected in series with a 45 V battery. What is the current in the circuit?

$R_T=15\ \Omega+15\ \Omega+15\ \Omega+15\ \Omega=60\ \Omega$
$V=IR=45\ V$
$\text{R}=60\ \Omega$
$\text{I}=0.75\ A$

Interactives:

- http://go.uen.org/b4m Series Circuits: Resistance
- http://go.uen.org/b4u DC Circuit Builder:Series Circuits: Voltage Drop

Check for Understanding

1. There are three 20.0 Ω resistors connected in series across a 120 V generator.
   a) What is the total resistance of the circuit?
   b) What is the current in the circuit?
   c) What is the voltage drop across one of the resistors?

2. A 5.00 Ω, a 10.0 Ω, and a 15.0 Ω resistor are connected in series across a 90.0 V battery.
   a) What is the equivalent resistance of the circuit?
   b) What is the current in the circuit?
   c) What is the voltage drop across the 5.00 Ω resistor?

3. A 5.00 Ω and a 10.0 Ω resistor are connected in series across an unknown voltage. The total current in the circuit is 3.00 A.
   a) What is the equivalent resistance of the circuit?

b) What is the current through the 5.00 Ω resistor?
c) What is the total voltage drop for the entire circuit?

Video extension and questions: http://go.uen.org/b4n

1. How do the voltage drops across the two light bulbs in the video relate to the total voltage drop for the entire circuit?
2. In the video, what was the assumed voltage drop for the connecting wires and the switch?
3. What was the current through the second light bulb as compared to the current through the first light bulb?

Answers to Check for Understanding

1.

a) $20.0\ \Omega + 20.0\ \Omega + 20.0\ \Omega = 60.0\Omega$
b) $120\ V/60\Omega = 2A$
c) $20.0\Omega \times 2A = 40V$

2.

a) $5\Omega + 10\Omega + 15\Omega = 30\Omega$
b) $90V/30\Omega = 3A$
c) $5\Omega \times 3A = 15\ V$

3.

a) $5\Omega + 10\Omega = 15\Omega$
b) 3A; current is the same throughout the circuit
c) $15\Omega \times 3A = 45V$

Summary

- A series circuit is one in which all of the current must pass through every resistor in the circuit.
- $V_T = V_1 + V_2 + V_3$
- $I_T = I_1 = I_2 = I_3$
- $R_T = R_1 + R_2 + R_3$

PHYSICS BOOK GLOSSARY

- Acceleration: A change in velocity, divided by change in time.
- Average velocity: average displacement divided by time in which the displacement occurred.
- Balanced forces: when the net sum of all forces acting on a body equals zero.
- Conduction: the transfer of heat through direct contact.
- Convection: the transfer of heat through currents in a fluid.
- Diffraction: bending of a wave around an obstacle or through an opening in an obstacle.
- Displacement: the difference between final and initial positions.
- Distance: a scalar quantity giving the positive length between two points frame of reference.
- Doppler Effect: change in the frequency and pitch of sound that occurs when the source of the sound is moving relative to the listener.
- Elastic potential energy: is the potential energy of an object due to its shape. It results when an object is either stretched or compressed, depends upon spring constant k.
- Electric charge: physical property of particles or objects that causes them to attract or repel each other without touching; may be positive or negative.
- Electric force: attractive or repulsive interaction between any two charged objects.
- Electromagnetic spectrum: the range of all types of electromagnetic radiation; the range of wavelengths or frequencies over which electromagnetic radiation extends.
- Electromagnetic wave: transverse wave consisting of vibrating electric and magnetic fields that can travel across space.
- Energy: the capacity for doing work; may exist as potential, kinetic, thermal, chemical, electrical, nuclear, and other various forms.
- Energy conversion: process in which energy changes from one type or form to another.
- Force: a push or pull; an interaction between two objects.
- Frame of reference: refers to something that is not moving with respect to an observer that can be used to detect motion or describe from which perspective the problem is to be solved.
- Free-Body Diagram: a picture that shows all of the forces acting on an object. Usually referred to as a Vector Diagram.
- Frequency: the number of waves that pass a fixed point in a given amount of time.

- Friction: the rubbing of one body against another; while it often opposes motion that is not always the case.
- Gamma ray: A photon of electromagnetic radiation of very short wavelength, less than about 0.01 nanometer, and very high energy; can be used to treat cancer; studied by astronomers.
- Gravitational force: the force of attraction between all masses in the universe.
- Gravitational potential energy: depends on an object's weight and its height above the ground. (GPE= mgh= mass x gravitational acceleration x height).
- Gravity: the force that attracts a body toward the center of the earth, or toward any other physical body having mass.
- Infrared: having a wavelength just greater than that of the red end of the visible light spectrum but less than that of microwaves. Infrared radiation have wavelengths from about 800 nm to 1 mm, and is emitted particularly by heated objects.
- Instantaneous velocity: the velocity at a specific time.
- Kinetic energy: energy of moving matter.
- Law of conservation of energy: states that the total energy of an isolated system remains constant—it is said to be conserved over time. Energy can neither be created nor destroyed; rather, it transforms from one form to another.
- Law of universal gravitation: law stating that gravity is a force of attraction between all objects in the universe and that the strength of gravity is greater when masses of objects are greater or distances between objects are shorter.
- Mass: amount of matter in an object.
- Mechanical wave: is a disturbance in matter that transfers energy through the matter. There are three types: transverse, longitudinal, and surface waves.
- Medium: the matter through which the wave travels.
- Microwave: an electromagnetic wave with a wavelength that ranges from 0.001–0.3 m, shorter than a normal radio wave but longer than those of infrared radiation. Microwaves are used in radar, in communications, and for heating in microwave ovens and in various industrial processes.
- Net force: the overall force on an object when all the individual forces acting on the object are added together.
- Normal force: support force exerted upon an object that is in contact with another stable object.
- Period: the amount of time for harmonic motion to repeat itself, or one full cycle, represented by T.
- Position: location of an object, usually relative to where movement started or ended.
- Potential energy: stored energy an object has because of its position or shape.
- Radiation: the transfer of energy through electromagnetic waves.

- Radio wave: an electromagnetic wave of a frequency between about 104 and 1011 or 1012 Hz,or larger than 10 cm; used for long-distance communication.
- Rate: change in the measurement of units with respect to the change in another measurement (which is typically time).
- Reflection: bouncing back of waves from a barrier they cannot pass through.
- Refraction: bending of waves as they enter a new medium at an angle and change speed.
- Scalar: a description of motion referring only to magnitude (e.g. distance, speed).
- Speed: Total distance traveled divided by total travel time.
- Speed of light: speed at which all electromagnetic waves travel through space, which is3.0×108 m/s.
- Time: measurement of a period in which something occurred, is occurring, or will occur
- Ultraviolet: part of the electromagnetic spectrum having a wavelength shorter than that of the violet end of the visible spectrum but longer than that of X-rays. Wavelengths range from 10 nm to 400 nm.
- Vector: a description of motion referring to both magnitude and direction (e.g. displacement, velocity) a quantity that has a direction and a magnitude.
- Vector diagram: (also sometimes called a force diagram or free-body diagram) a sketch showing all of the forces acting on an object; used by physicists and engineers to analyze the forces acting on a body.
- Velocity: Change in position divided by change in time.
- Visible light: part of the electromagnetic spectrum that can be detected by the human eye. The wavelengths associated with this range are 380 nm to 750 nm. (1 nm = 10-9m)
- Wave: an oscillation accompanied by a transfer of energy through a medium.
- Wave amplitude: is the maximum distance the particles of the medium move from their resting positions when a wave passes through.
- Wave frequency: the number of waves that pass a fixed point in a given amount of time.
- Wavelength: is one way of measuring the size of waves. It is the distance between two corresponding points on adjacent waves, and it is usually measured in meters.
- Weight: another name for the force of gravity.
- X-ray: an electromagnetic wave with high energy and a very short wavelength, ranging from 0.01nm to 10 nm.


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